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1855

Marine Corps Research University

Interim Reports (Volume II)

Integration of Diagnostics into Ground Equipment Study

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TO SATISFY THE REQUIREMENTS OF

MCRU Contract No. M67004-99-0037
Delivery Order No. 086

APPENDIX 8.6

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Interim Report 1

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21 October 2003

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1 Introduction

1.1 Task Description

The Marine Corps is transitioning into a new form of logistics support. Traditional means of support are being amended to take advantage of computer, sensor and communications technologies to provide efficiencies in combat service support. This project will review what technologies are available to support the Marine Corps logistics transformation effort and how these technologies can be implemented in the maintenance and supply (components of CSS) of ground equipment.

To conduct a review of the sources of autonomic logistics data, the requirements of what that data should be, the timeliness or required "pull" of such data, its transmission means in garrison and in the field (afloat or ashore), the availability of current or planned logistic systems to receive data, and what Decision Support Tools (DSTs) would be used to transform the data into the necessary information by which timely and long-term support decisions can be made as part of Total Ownership Cost (TOC) of the LAV family of vehicles. The study will recommend standards for the Corps to apply across the existing and planned end item regarding diagnostic sensor integration as designated by the Sponsor and provide a programmatic roadmap on how autonomic logistics data can support future maintenance and supply side USMC logistics systems.

The draft Statement of Work (SOW) provided by the Sponsor for this effort was narrowed in scope to focus on one major end item. PSU performers will address the USMC logistic efforts with all of the known functions and components and develop a support template for sea-based logistics to the selected end item. PSU proposes to evaluate the LAV family of vehicles as the one (1) selected USMC end item. By focusing on the feasibility of integrating diagnostics on one (1) representative system, this effort can then by analogy and similarity address the broader requirements articulated in the SOW.

This effort is broken down into the following tasks that will be executed concurrently:

Task 1: Literature Review Task 1.1: Review all pertinent USMC logistics information on one (1) selected USMC end item. This will include reviewing legacy logistics support systems, current operating procedures and future support concepts to include the Integrated Logistics Capability (ILC) for incorporation on the selected system.

- Task 1.2: Review of technologies that do or could support maintenance diagnostics for the selected USMC equipment.
    - Task 1.2.1: Review of data processing technologies that do or could support predictive maintenance actions and/or failure modes on the selected USMC end item.
    - Task 1.2.2: Review trend analysis/decision technologies that would assist USMC logistics managers in initiating/maintaining end item reliability situational awareness.

Task 2: Maintenance Data Implications. Review one selected USMC end item. Selected based on span of life-cycle acquisition stages.

- Task 2.1: Review what types of maintenance data that is currently being generated. Review the sources of this data, means of data generation, how the data is stored/catalogued/reviewed/acted upon.
- Task 2.2: Review the selected end item for the types of sensors/diagnostic tools needed to facilitate system diagnostics/failure analysis.
- Task 2.3: Based on the results of tasks 2.1 and 2.2, recommend a standard maintenance data protocol for USMC end items. The recommended approach will include the following:
    - What data is required?
    - How the data will be generated/stored/used.
    - Recommendations on what data system and communication technologies are available to implement the approach.
    - A recommendation on what data representation and data recognition tools are available to transform data streams into useable information.

Task 3: Logistics Systems Information. Based on results of tasks 1 and 2, review the suitability of current and future logistics systems to use the maintenance information generated to make logistic support decisions for the selected USMC end item and future systems.

- Task 3.1: Determine the quantity/quality/timeliness of information to be used at:
    - The unit/end item level
    - The Marine Expeditionary Brigade (MEB) level
    - The HQMC/SYSCOM/MCLC level
- Task 3.2: Review candidate decision tool technologies and recommend which are most suitable for implementation.

Task 4: Establish Universal Data Support Requirements.

- Task 4.1: Identify data support functions for multi-sensor prognostics integration for the selected end item.
- Task 4.2: Recommend candidate web based technologies to facilitate multi-sensor prognostic integration for the selected end item.

Task 5: Identify Critical Path and Risks for One (1) Candidate System. Interpret and correlate the results of tasks 1-4 and depict/present the information in a way that identifies a critical path for implementation of a USMC Autonomic Logistics Support System by FY 2008.

1.2 Envisioning IDGE

We envision an IDGE system as the driver for the tasks we must engage in. These include the identification of data requirements, identification of tools and techniques that may facilitate the eventual creation and deployment of such a system, and the organizational constraints e.g. OA processes being worked on as part of other efforts

under way at the Marine Corps. The envisioned system should also take into account current work in the areas of autonomous logistics, condition-based maintenance, and respond to trends such as sea-basing. Using this approach is useful because it allows members of the research team an opportunity to develop a shared vision, one that can then permeate the distributed efforts of the team members. The vision also allows a means of communicating with the clients and potential users. It becomes a strawman that can guide discussion, operationalization and debate about the form the system will assume in the future.

1.2.1 A Preliminary Definition

The proposed IDGE system is a means to accomplishing efficient and autonomous Condition Based Maintenance (CBM). It is meant to be a bridge between the actual physical sensors installed on deployed ground equipment and the Operational Architecture (OA)/ logistics processes involved in supporting the Marine Corps operations [Appendix 1]. The diagnostic system attempts to process the information from the sensors intelligently, and to optimally facilitate and automate the triggering of the appropriate logistics processes. This concept is called Autonomic Logistics (AL). Additionally, the diagnostic system also attempts to integrate the multiple, complex, stove-piped processes in the logistics chain with a view to making them cross functional and efficient. This concept is termed as Integrated Logistics Capability (ILC).

1.2.2 The Boundaries around IDGE

The IDGE system, thus, is an intermediary between the ground equipment sensors and the OA processes. Hence, these can be considered as the boundaries that scope the system.

1.2.2.1 Sensor Architectures

The Figure 1.1 shows the conceptual depiction of the sensor architecture on an LAV and connectivity to the Integrated Data Environment [2].

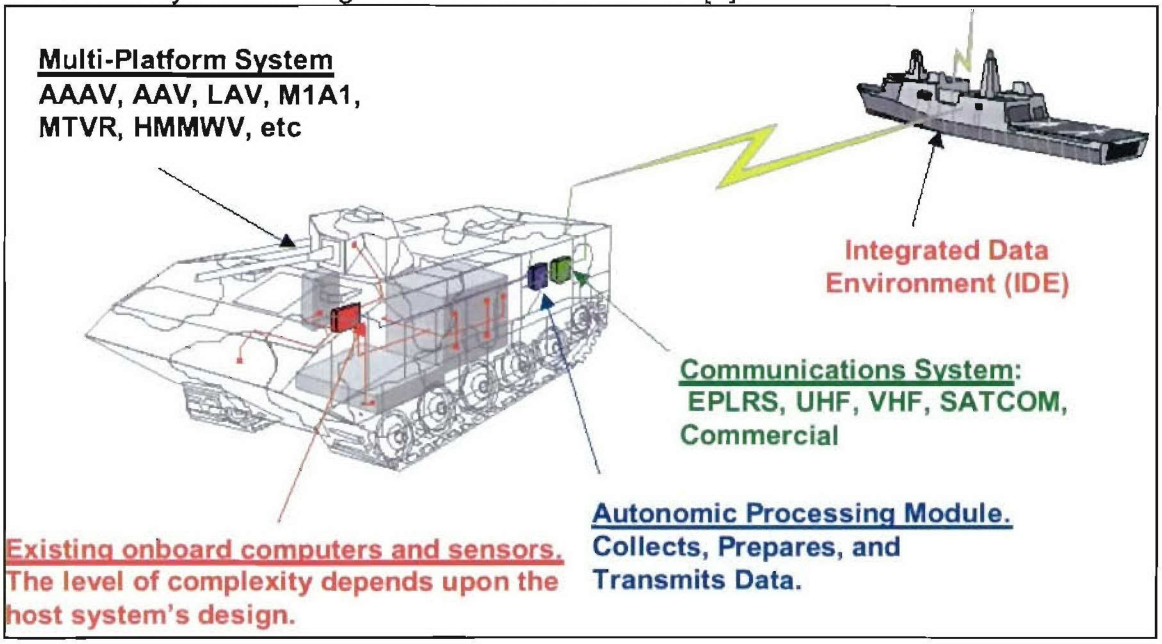

Figure 1.1: Sensor architecture depiction [2]

The types of data transmitted from the LAV, via the communications system, include location, fuel levels, system health and ammunition levels. GPS satellites will primarily serve in tracking the location of the LAV. Fuel levels and system health can be gauged from on board computers and sensors that are constantly measuring multiple physical parameters such as vibration, stress and strain, pressure, acceleration etc which are then encoded and wirelessly transmitted to the active/ passive sensor signal analyst - entry point to the IDGE system. These parameters are then compared with threshold values stored in a database for the diagnosis/ prognosis of the component.

Wireless sensors provide new opportunities to foster the push to develop prognostics/ diagnostics for the ground equipment. Reference [10] gives further information on the different wireless sensing topologies that can be employed.

1.2.2.2 Operational Architecture Processes

The Marine Corps' existing supply chain includes more than 200 individual systems to support ground logistics, called Automated Information Systems (AISs), with almost no integration among them [3]. The same processes were used to acquire and manage

virtually all types of inventory, regardless of an item's strategic importance. Demand-signal information was not shared up and down the supply chain, nor was total-asset visibility available for such items as inventory and equipment. This lack of information meant the USMC needed a lot of inventory per requirement that tied up significant capital resources that could be used for other strategic purposes, such as new-weapons development. AISs utilize a combination of in house developed application software, Government Off-the-Shelf (GOTS) products, and Commercial Off-the-Shelf (COTS) products [4]. Many of these systems were originally designed to support stove-piped logistics functions and processes of the 1960's. As time passed, lack of an overall development plan created multiple systems with overlapping capabilities. These systems utilize a wide range of information technology, much of which is aging and difficult to integrate. Integration has been accomplished in the past through a rapidly increasing number of point-to-point interfaces, which are difficult to maintain over time and unreasonably complicated by the unplanned data environment.

The consolidation of these legacy information systems, currently used to support ground logistics, by migrating to a smaller number of systems without loss of functionality, is the primary objective of the USMC. The migration and retirement strategies for transition from a very large number of legacy applications, data stores, and interfaces to a much smaller number of primarily COTS-based systems in a shared data environment is called System Realignment and Categorization/Consolidation (SRAC) and is shown in the figure below.

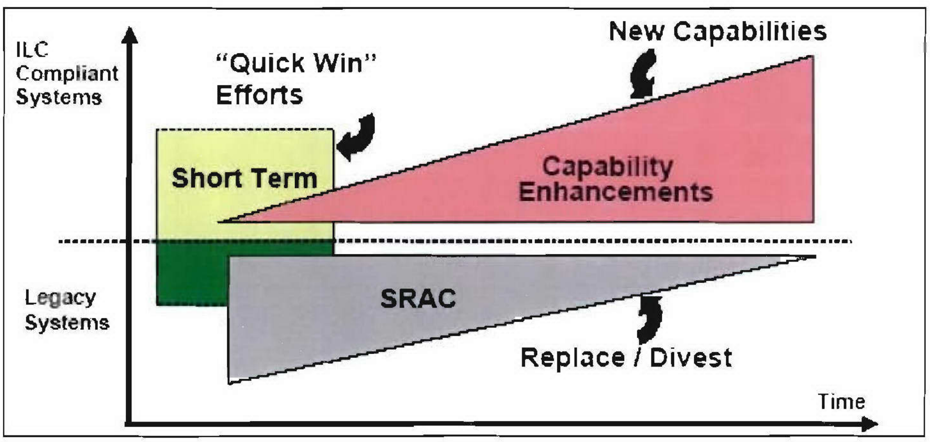

Figure 1.2: ILC Information System Transformation [4]

A detailed operational architecture has been delivered to the USMC by Sapient, a business and technology consultancy, which reduces the 200-plus logistics applications to a much smaller number of integrated web and wireless applications [3]. The anticipated outcomes are a leaner support structure that will free up 1,800 Marines from logistics duties and make them available for other purposes; faster deployment capability resulting from a 20 to 70 percent reduction in the tonnage it needs to ship; a one-time reduction in inventory of 45 to 61 percent; inventory cost savings of between

$125 million and $180 million every year; and a 35 to 50 percent reduction in order cycle time for products and services.

The U.S. Marine Corps is also currently working with content management software vendor Enigma Inc. in an effort to streamline OA processes including maintenance and repair work on LAVs that are designed for battlefield use [1]. The Marines plan to use the Enigma 3C Platform software to develop a series of interactive technical manuals so LAV crews can diagnose problems and make in-the-field repairs to their vehicles. The electronic manuals will provide online access to service information and parts catalogs for all LAV models. In addition, the software will be linked to onboard diagnostics and configuration management systems, as well as parts-ordering and inventory management applications. These links will let the Marines stockpile spare parts for the LAVs and then rapidly deliver them to vehicle crews as needed.

1.2.3 An Envisioned System for IDGE

Based upon the descriptions of the system boundaries, the overall picture of an envisioned IDGE system would resemble Figure 1.3 below [9].

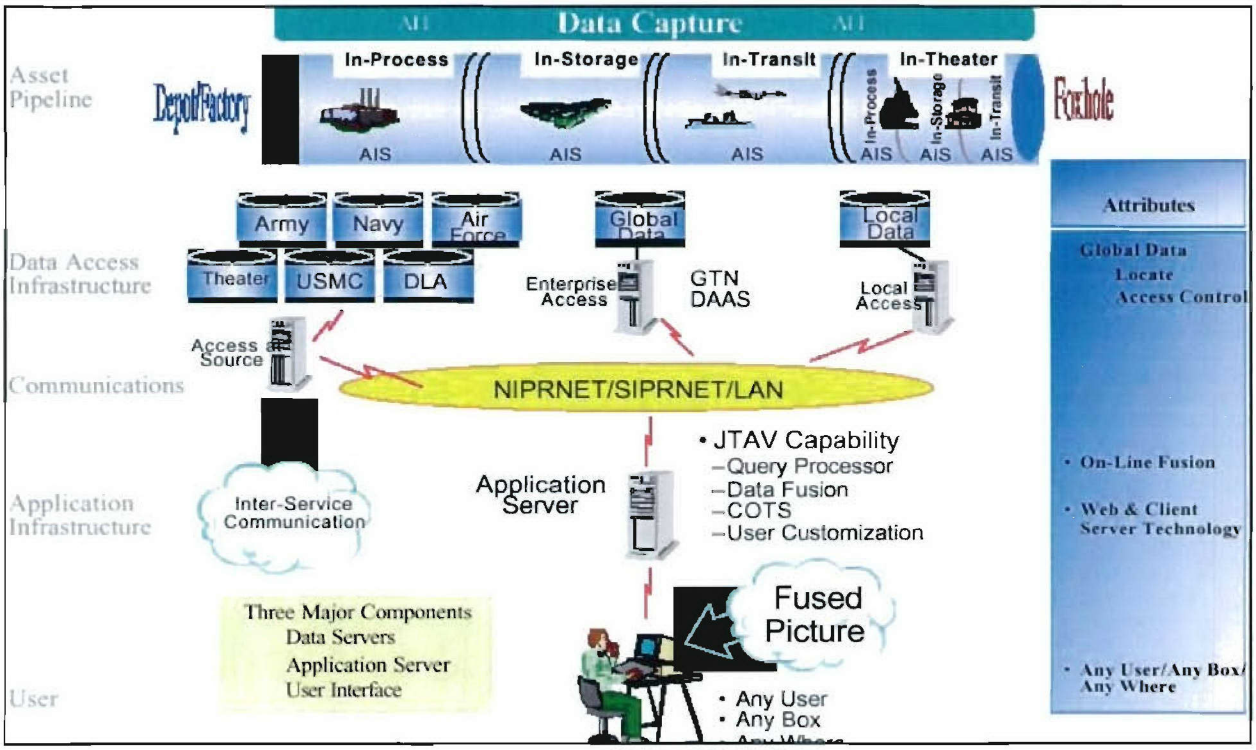

Figure 1.3: Overall system architecture [9]

The point of connectivity between the sensor architecture and the IDGE system is the sensor signal analyst, who could be an automated system or a human. The sensor signal parameters are retrieved and then compared with threshold values, that are

predetermined for each component in the LAV. Depending on the result, the appropriate action is taken. These threshold values can take the form of the active lifetime of a component, allowable stress values etc. If the retrieved values are exceeding or close to exceeding the failsafe limits (typically fixed at 10% below ultimate thresholds), then the request management process in the set of OA processes has to be triggered. A corrective action in the form of repairs or replacements is warranted. Further, when such a corrective action is taken, it needs to be recorded and the component history database has to be updated to reflect the change. Typically, this involves resetting the threshold values for the component.

The corrective/ maintenance action can be carried out by any of three levels of maintenance, and it is imperative that the escalation procedures be carried out to ascertain which level handles the problem. This is done on the basis of an SMRC code, which is assigned to the problem by the first troubleshooters/ analysts. A description of these 3 hierarchical levels is explained in Chapter 3.3.2.

The detailed functionalities of the IDGE system along with the personnel/ systems interacting with it, shall be manifested in the form of uses cases and actors, respectively, using the visual modeling tool of Rational Rose.

2 Marine Corps (MC) Background Information

In order to achieve the goal of this project, the team has to thoroughly understand the current and developing systems in USMC. This initiated a survey of literature for the following systems –Operational Architecture, SCOR model, Autonomic Logistics (AL), GCSS-MC and Integrated Logistics Capability (ILC). The detailed summary related to all these can be found in Appendix: 1.

The ‘to-be’ logistics system for the USMC aims to realize the following:

- Provide overall direction to the re-engineering efforts and align the various systems by making the necessary tradeoffs between requirements, solutions and funding so as to ensure optimal results.
- Ensure that the requirements of the War-fighter are translated into system and functional requirements.
- Ensure that the developed solution meets the requirements and forms the best fit for the Marine Corps in terms of reliability, robustness, economy and culture.

Developing a blue print by identifying the requirements as well as solutions calls for a systematic and standardized approach. The requirements have to be identified along the three fundamental perspectives – operational view, systems view and the technical view. Aligning the system along all these three views will ensure uniformity and consequently inter-operability within the different organizations of the USMC.

The architecture can therefore be described as a combination of these three different views. The operational architecture view is a description of the tasks and activities, operational elements, and information flows required to accomplish or support a mission. The systems architecture view is a description of systems and their interconnections providing for or supporting the war-fighting functions. The technical architecture view describes the enabling technologies and concepts that govern the arrangement, interaction and interdependence of the different systems. The review of relevant literature shows that the operational architecture view has been developed for application across the USMC.

The operational architecture description identifies the customer as the ultimate consumer of the products/services. The customer's main responsibilities include demand generation, operator level maintenance and accounting for their resources. Demand could be reactive such as unscheduled maintenance or forecasted such as scheduled inventory replenishment. The customer requests are passed on to a single entity through manual or autonomous modes. This entity (S1) is responsible for the detailed logistics chain processes including managing orders, sourcing and delivery. The sourcing and transportation decisions can be made by S1 only if real-time data about the requirements and the potential source of supply across the enterprise is available. This requires sharing of data among different entities with S1 and can be enabled by a Shared Data Environment (SDE) [Refer Figure 11.5 in Appendix: 1]. This facilitates the flow of data throughout the enterprise and provides visibility of the assets

in transit and in processing. It also renders real-time or near real-time analysis of the information at each node within the logistics chain. Refer Appendix: 1 for a detailed description.

The conceptual ideas discussed above emerge from the philosophy behind the ILC that is to enable the maintenance of a shared data environment and further enterprise-wide planning based on real time and accurate information, so that the holistic metrics of a global supply chain can be optimized. The ILC aims to transform the mode of operations within the USMC to meet the challenges of tomorrow. The transformation strategy is based on best practices within the industry and would provide a framework for the execution of agile and effective logistics support. The key enabler of the ILC concepts is information technology. The ILC thus envisions a family of systems that provides information interoperability across the combat support functions and between combat support and the command & control functions in support of the joint war fighter.

Thus the GCSS would be the war fighter's tool to capture essential data, transform it to usable information and gain information superiority to the success of maintaining force readiness and winning nation's conflict. It would be a flexible tool that would enable a seamless transition between peacetime and contingency operations.

The essential attributes envisioned within the GCSS are listed below:

- Common operating environment for all the elements (computers) that will help overcome the incompatibility of different operating systems.
- Common interface/screen that will enable any authorized user to comprehend the information, this would also reduce the training required.
- Availability of all war fighter functions from a single workstation. Integration of information across functional areas, combat support and command & control.
- Common services such as printer, sound and communication interfaces with the COE, forms and report generators, database searches, data extraction and business process servers.
- Robust communications infrastructure.
- Access to the GCSS should be available from any geographic location.

The GCSS would merge with the Global Command and Control Systems (GCCS) wherein GCSS would enable commanders to provide military information rapidly to the National Command Authorities (NCA) and to other supporting commands. The GCCS concentrates heavily on the operations while the GCSS would focus on the combat support or logistical requirements of the war fighter. The convergence of both these systems will provide situational awareness via near real-time view of the battlespace for any mission.

3 Maintenance

3.1 Overview on Maintenance

3.1.1 Maintenance

Maintenance is an essential part for any system/plant for sustainability of the system/plant. Monitoring plays a significant role in maintenance. Depending upon the type of maintenance requirements (scheduled, anticipatory or critical) monitoring and maintenance efforts are closely inter-related.

Figure 3.1 provides features of maintenance related to monitoring.

3.1.2 Various Maintenance types related to Monitoring

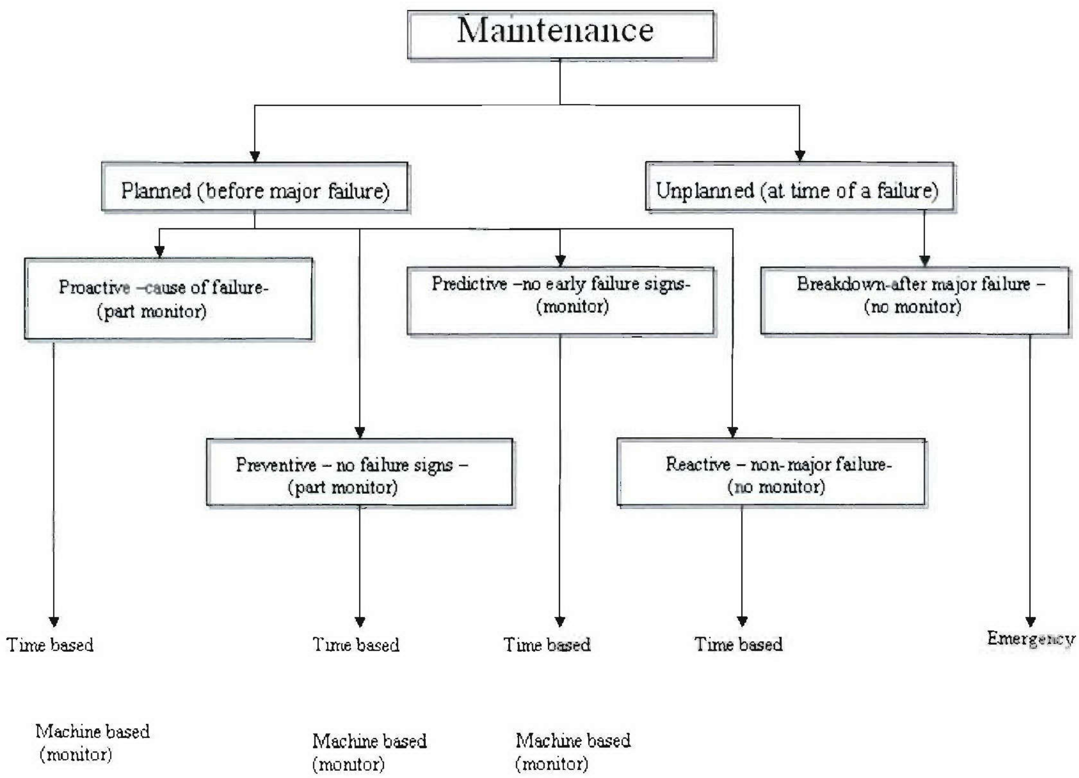

Figure 3.1: Types of Maintenance related to monitoring

The following list explains in-detail the various types of maintenance [12]:

1) Maintenance: examines the system operations efficiently; replaces the features/component(s) that looks like or soon to be worn out and to bring them to "as-new" condition. It includes repairing, replacing and servicing.

2) Breakdown maintenance: also called as "failure maintenance". This type of maintenance comes into action after the system/component(s) have failed. It is an unplanned event (maintenance) which results in high cost and also not appealing to the maintenance personal because of the inconvenient work timings.

3) Condition-based maintenance: refer- proactive, preventive and predictive maintenance.

4) Corrective maintenance: This maintenance is based on "performance monitoring". When performance of a system drops, a certain amount of maintenance has to be ensured in order to maintain the system in its "best condition". This type of maintenance is expected and has to be planned in advance. It could be considered as a combination of breakdown (unplanned) or reactive maintenance.

5) Failure maintenance: refer- breakdown maintenance.

6) Fixed-time maintenance: refer – reactive and time-based maintenance.

7) Improvement maintenance: refers to the maintenance that involves modifications and re-designing within the system.

8) Machine-based maintenance: It relates to maintenance before any breakdown i.e., before any deterioration or after the early stages of failure become detectable.

9) On-condition maintenance: It is a combination of proactive, preventive and predictive maintenance.

10) Planned (or schedule) maintenance: In a system, this type of maintenance is considered to be essential and is scheduled to occur during systems operation. For example, a maintenance manager and team are appointed and they operate at the most convenient time.

11) Predictive maintenance: By able to predict the future deterioration of a component from past information, this type of maintenance will be able to determine the most convenient time for maintenance to be undertaken. This is done either by examining the component at frequent intervals or by using continuous monitoring methods.

12) Preventive (or preventative) maintenance: By taking a deteriorating current situation into action, this type of maintenance is undertaken to prevent any further worsening. It requires a certain amount of monitoring to provide sufficient evidence to consider action at the best time; however, it could be time based.

13) Proactive maintenance: By monitoring components which cause or prone to fail – rather than considering early signs of failure –a suitable maintenance action could prevent any commencement of deterioration. It is considered to be the most valuable monitoring technique available.

14) Reactive maintenance: This type of maintenance is more predominant for replacing the components that have already failed. It can be acceptable.

15) Reliability-centered maintenance: It is considered to be a machine-based maintenance, which encompasses all planned maintenance under the examination of the complete failure of complex component. It is based on the inherent reliability of each item of equipment when used in its correct operating state.

16) Time-based maintenance: sometimes called as "fixed-time maintenance". From past experience, and from careful analysis or guesswork if the system is new, a schedule of maintenance is organized so that at certain fixed intervals each part of the system is appropriately maintained.

17) Total productive maintenance: This idea of maintenance is designed to provide a continuous improvement in production. In general, production drops with time due to deterioration of the component and lack of personal interest. The objective of this maintenance is to promote interest and involvement from a variety of personnel in-group activity. This will lead to consider maintenance seriously and will include functions like routine inspection, cleaning and equipment problems to be solved in a cooperative manner.

18) Unplanned (or unscheduled) maintenance: Suppose a component fails to function due to some fault, then an emergency team will be hurriedly formed and asked to put the matter right immediately, however inconvenient it may be. It is run on emergency lines.

For our study we deal with three classes of maintenance practices:
1. Scheduled (Refer No. 10 in the above list)
2. Anticipatory (Refer No. 12 in the above list)
3. Critical (Refer No. 2 in the above list)

Literature abounds with information on Scheduled and Anticipatory maintenance. The most critical part of these is how the maintenance plans are implemented. Therefore, we do not go to the background literature on these two. However, in our framework we

will discuss how these needs to be incorporated in the MC maintenance functions. In the next chapter, we detail our science-based approach for anticipatory maintenance.

3.2 Anticipatory Maintenance: Research based Preliminaries

3.2.1 Introduction and Definitions

Anticipatory Maintenance (AM) comprises of Monitoring, Diagnosis, Prognosis and Control. The word diagnosis is defined as a judgment that is the result of the act of discovering the current nature of a fault by making a careful examination. Prognosis is a judgment about the future status based on available information and experience. To be intelligent is to possess powers of learning, reasoning, and / or understanding, especially to a high degree [16].

Desired capabilities of a system that can accurately diagnose the current equipment conditions and make predictions about its future behavior are:

1. On-line Monitoring of an equipment with minimal supervision
2. Detection of a fault initiation before catastrophic breakdown occurs
3. Diagnosis: Identify the type of a failure and perform reasoning / interpretation of the current condition
4. Prognosis: assess the evolution of the faulty condition, predict time-to-failure and invoke corrective action if necessary.

We identify the above four as the key issues and efforts that need to be critically examined for building an Anticipatory Maintenance Framework for Marine Corps Ground Equipment. Several disjoint disciplines such as digital signal processing (DSP), wavelet theory, and pattern recognition including neural networks, multi-sensor fusion, and statistical forecasting methods are critical to such a system development. We consider a LAV as an example to build the Integrated Diagnostics framework. LAV's are equipped with on-board sensors and we can assume (we relax this assumption when we build the IT framework) that the processing of sensor data is done by on-board processors.

Figure 3.2 shows the high-level systematic framework of AM without considering interfaces to AL. At this level AM composes of six basic steps: (1) Sensor data acquisition, (2) Exploratory analysis, (3) Signal preprocessing, (4) Sensor data representation, (5) Diagnosis, and (6) Prognosis.

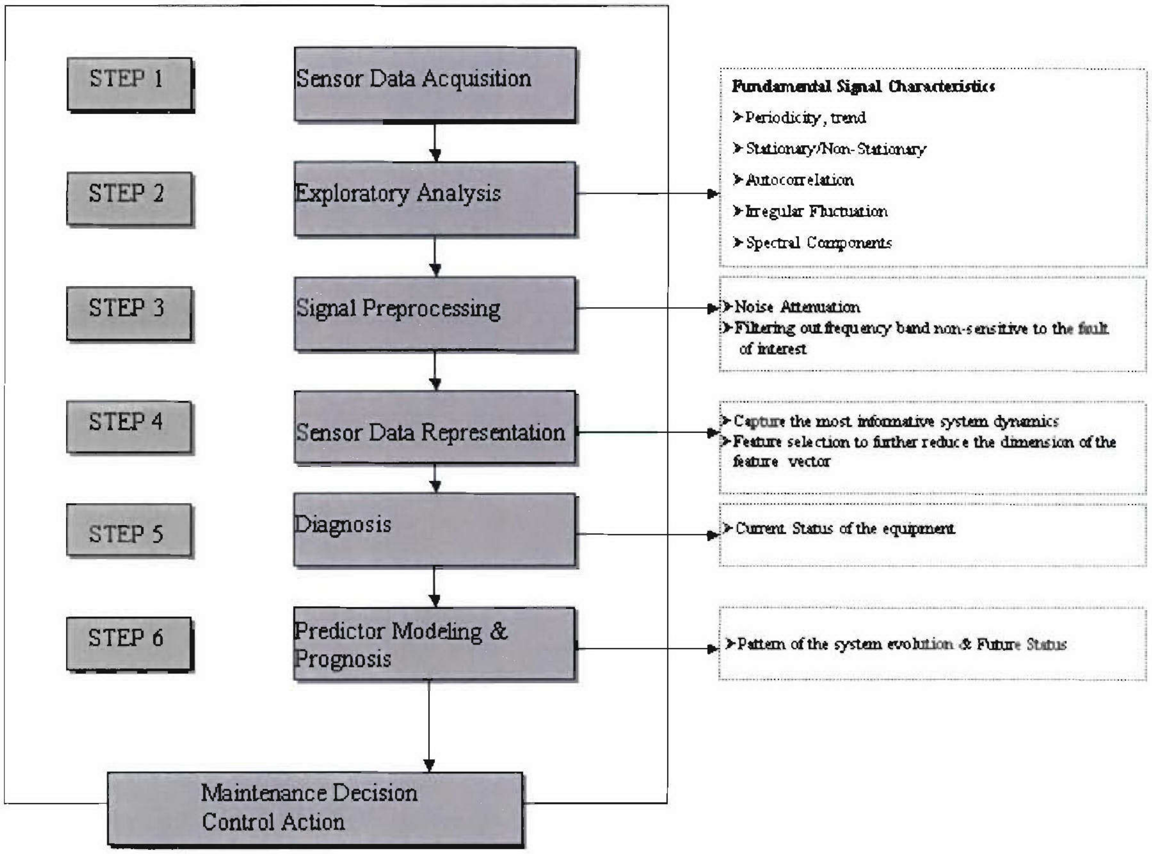

Figure 3.2: Schematic Diagram of AM

Diagnosis can be performed through the utilization of on-line sensing devices. The required information on the present condition of the LAV is collected (monitoring) using different types of sensors such as force, vibration, battery condition, and acoustic emission, etc. In a complex system such as LAV, a suite of different types of sensors is often employed and they provide multiple monitoring features. A multi-sensor fusion technique can be employed in such a case to remove redundant information and to combine imprecise information from multiple sensors to obtain accurate and concise features[16].

Exploratory analysis is a very important step since it can reveal substantial characteristics of the signals in advance. Without understanding the fundamental attributes of the signal under consideration, it is impossible to select an appropriate signal representation scheme reflecting the underlying dynamics of signal accurately, leading to poor diagnosis and prognosis performance consequently.

The right choice of a representation scheme could not be emphasized less because the success of diagnosis and prognosis depends on the robustness (accuracy) of features extracted out of the signal representation scheme. Effective sensor data representation must be not only matching with the structural characteristics of the

signals under consideration, but also it has to provide the parsimonious and accurate information to be used for fault (anomaly) detection and prediction. A diagnosis system on an LAV equipped with an efficient feature extractor / compressor will be able to provide condensed information sensitive to the current condition. Given the features, diagnosis establishes the relationship between the monitoring features and the status of LAV.

Prognosis for an observed system (a component, sub-assembly of LAV) requires accurate forecasts of the future behavior of a particular component of the LAV. The ability to accurately predict the time evolution of the system makes it possible to determine the future status of the system and to provide an indication of failure precursors, leading to the enforcement of maintenance actions. During the ongoing fault evolution process, initiation of a specific fault must be detected and confident prediction on the fault evolution in the near future will be required to be made before the magnitude of a failure-state-index reaches maintenance techniques that are postmortem approaches, an ideal AM will monitor LAV components continuously through on-line sensors. Based on the sensor data, AM will trigger the diagnosis and prognosis modules where current status and remaining life of the component/sub-assembly are estimated.

In developing the signal representation scheme, the following issues need to be addressed:

1. How to represent sensor signals in such a way that the extracted features – usually lie in a transformed domain with respect to certain basis – contain significant information useful for the early detection of the fatigue crack growth and gear tooth breakage.
2. How to obtain a set of parsimonious features which are able to not only capture the transient nature of sensor signals, but also conserve both time and frequency information essential for prognosticating the time remaining to failure.
3. How to effectively fuse and project the multiple features into decision space such that derived judgment on the current and future status of a component is reliable and immune to environmental noises.
4. How to identify and track the evolution of faulty conditions and how to establish a prediction model therefrom.

	Signal Characteristics			
	➢ Linear ➢ Stationary	➢ Linear ➢ Stationary ➢ Harmonic Response	➢ Linear ➢ Non-Stationary ➢ Harmonic Response	➢ Nonlinear (piecewise linear) ➢ Non-Stationary ➢ Non-Harmonic Response
Candidate Model	ARMA type time series models	Fourier Analysis	STFT	Wavelet Analysis
Information	Either Time or Spectral contents	Frequency contents only	Both time and frequency (fixed resolution)	Both time and frequency (Multi-resolution)

Table 3.1: Signal Characteristics and Corresponding Representation Scheme

We need to report on the suitability of a representation scheme for different sensors used on the LAV. Traditional techniques include time domain approaches and various spectral analyses. Often time, the heart of these methods are based on the Fourier transform. Since, most of the time, deviant vibration attributed to the defects in one or more components of the equipment have instantaneous shock impulses and exhibit transient (non-stationary) nature, traditional spectral analysis based on Fourier analysis is inadequate for the modeling of these disturbances that contaminate only a small fraction of the signal at a specific time instances. Wavelet transform has been proved to be more appropriate for analysis of such a signal. The Wavelet Transform (WT) is capable of decomposing a signal into different frequencies with different resolutions (Multi-resolution Analysis-MRA) [16], i.e., it provides a time-scale (frequency) representation of the signal. The power of the WT comes from the fact that WT is able to:

1. Conserve both time and frequency information
2. Capture transient nature (non-stationary) of a signal especially having periodic/quasi-periodic impulse train
3. Conserve signal energy in the transform
4. Compress a signal, i.e., neglect insignificant information, such that compact representation
5. Be reversible to time domain without significant loss of information content of the signal.

Figure 3.3 shows schematics of the scientific basis of AM. Each box indicates the step in the AM process along with the types of techniques applicable.

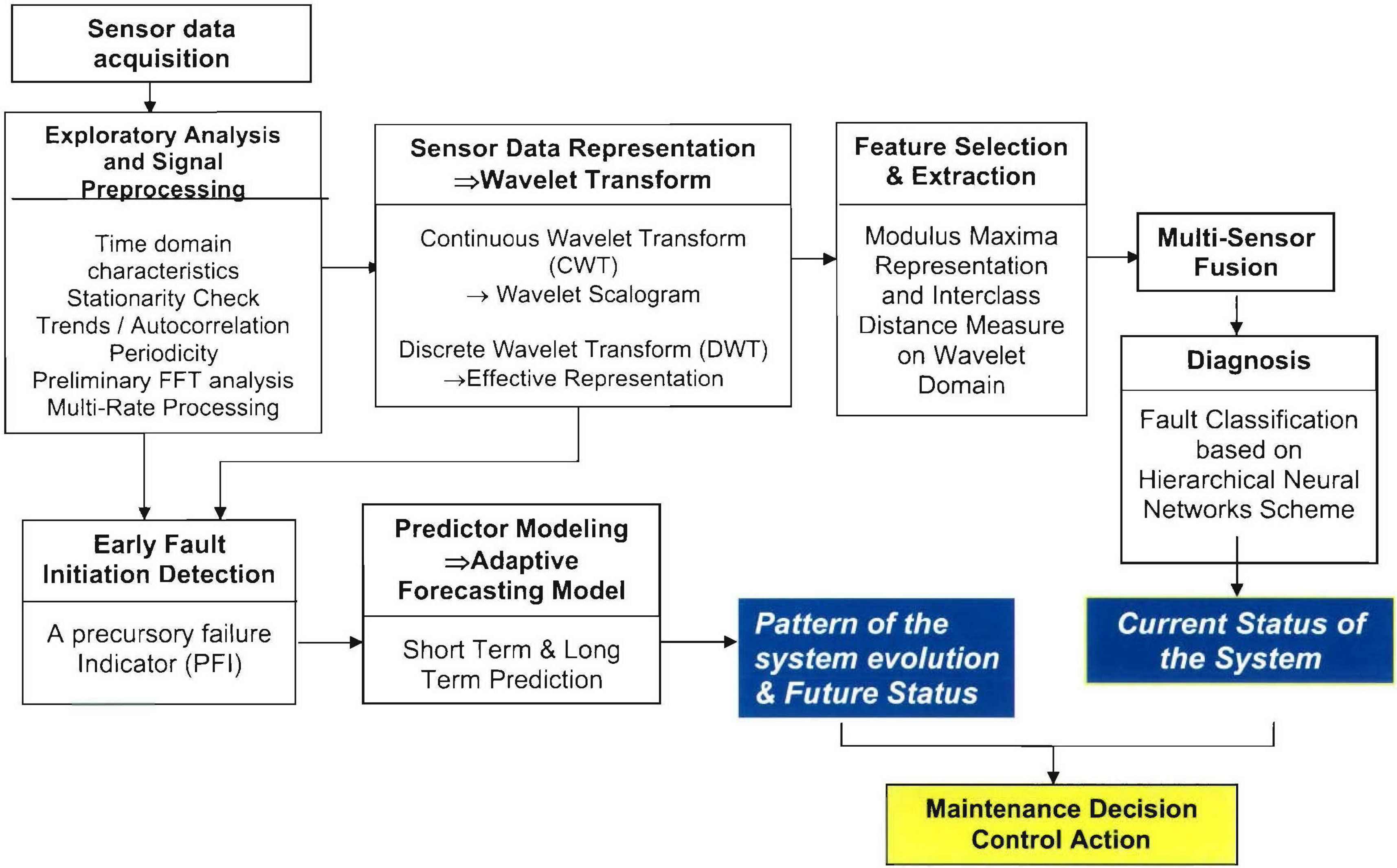

Figure 3.3: Schematic Diagram of AM

3.3 Maintenance performed in Marine Corps (MC)

3.3.1 Introduction and categories of Maintenance

Maintenance is considered to be a continuous and an essential event that will reduce the failure rate of a component for any kind of a system or equipment.

From the MC point of view, every unit performs maintenance and the unit commander is responsible to ensure that maintenance is performed periodically. Company grade officers are the primary personal officers who supervise the maintenance.

Maintenance Categories:

Maintenance is an action taken to restore a component in a serviceable condition. Functionalities of maintenance are Inspection, Testing, Servicing, classification as to serviceability, repair, rebuilding and reclamation. It also includes all supply and repair action to successfully carry out the mission.

Maintenance efforts are categorized into two types:

1. Preventive Maintenance (PM): Is performed to maintain the equipment in a serviceable condition or to prevent the item from becoming unserviceable. PM is a form of maintenance that the Marines routinely conduct and significantly enhance the equipment readiness, thus improving unit readiness.

2. Corrective Maintenance (CM): Is performed when a component of equipment no longer performs at 100 percent of its capability. This form of maintenance restores a failed component back to its serviceable condition and Marines with occupational specialties generally perform CM.

The aforementioned maintenance actions encompass the majority of unit's (organizational) maintenance operations.

3.3.2 MC Maintenance System Organization

The MC maintenance system is organized into three categories or levels and five sub-levels or echelons. Commanders are responsible to understand unit's organic maintenance capabilities as well as their supported units.

3.3.2.1 Levels and Echelons of Maintenance (EOM)

I. Organizational:

Maintenance normally performed by an operating unit on a day-to-day basis in support of its own operations. The organizational-level maintenance mission is to maintain assigned equipment in a full mission-capable status while continually improving the process. Organizational-level maintenance can be grouped under categories of "inspections," "servicing," "handling," and "preventive maintenance."

Echelon 1: (Operator Maintenance)
- Crew level servicing of vehicles and weapons
- Includes standard servicing of equipment, such as preventive maintenance service checks

Echelon 2: (Mechanics/Technicians)
- Performed by mechanics organic to the combat maneuver units, such as infantry battalions
- Include fairly simple repairs, such as removal and replacement of major items

II. Intermediate:

The intermediate-level maintenance mission is to enhance and sustain the combat readiness and mission capability of supported activities by providing quality and timely materiel support at the nearest location with the lowest practical resource expenditure. Intermediate-level maintenance includes limited repair of commodity-orientated components and end items, job shop, bay, and production line operations for special mission requirements; repair of printed circuit boards, software maintenance, and fabrication or manufacture of repair parts, assemblies, components, jigs and fixtures, when approved by higher levels.

Echelon 3 & 4:
- Broken equipment is transported back to INTERMEDIATE repair resident in MEF maintenance battalion, a part of FSSG (that provides intermediate logistics support in general to the entire MEF)
- Battalion's five companies perform maintenance for
  - i) Ordnance (from rifles to howitzers) – Ordnance Maintenance Company (OMC)
  - ii) Motor transport – Motor transport Maintenance Company (MTM)
  - iii) Electronics – Electronics Maintenance Company (ELMACO)
  - iv) Engineering equipment – Engineer Maintenance Company (EMC)-------- at the 3rd echelon maintenance
  - v) 4th echelon maintenance ---Battalion's General Support Maintenance Company (GSM) do more demanding work on major assemblies such as engines and transmissions.

The aforementioned companies are part of every maintenance Battalion.

III. Depot:
The maintenance that requires a major overhaul or a complete rebuilding of parts, assemblies, subassemblies, and end items, including the manufacture of parts, modifications, testing, and reclamation, takes place here. Depot maintenance serves to support lower categories of maintenance by providing technical assistance and performing that maintenance beyond their responsibility. Depot maintenance provides stocks of serviceable equipment because it has more extensive facilities available for repair than are available in lower maintenance activities. Depot maintenance includes all aspects of software maintenance.

Echelon 5:
- Maintenance performed at Marine Corps Logistics Base Albany, Georgia and Barstow, California

Depot Repairs include major operations such as rebuild and overhaul of the entire piece of equipment.

Reference No. 12 states that the following recommendations were made for the Marine Corps Logistics, 2005 – 2010 for EOM:
- Consolidation of most using unit supply responsibilities at the retail level;
- Movement of 2nd and 3rd echelons of maintenance to the intermediate level;
- Movement of 4th echelon maintenance and secondary reparable (secrep) management to depot level.

The afore-mentioned recommendations will be considered in our IDGE study.

3.3.3 MC Supply and Repair

This section focuses on supply and repair in the active part of the Fleet Marine Force (FMF) and the Marine Expeditionary Force (MEF) is the key combat element of the FMF.

MEF is composed of three major parts:
1. A ground division
2. An air wing
3. A provider for Intermediate Logistics (Force Service Support Group – FSSG)

There are three active MEFs:
1. I MEF – Camp Pendleton, California
2. II MEF – Camp Lejeune, North Carolina
3. III MEF – Okinawa, Japan

3.3.3.1 Repair and Supply in the FMF:

There are three maintenance levels and five echelons of maintenance (EOM). FMF Repair is performed in any of the five echelons of maintenance, four of which reside in the FMF. (Refer section 3.3.2).

3.3.3.2 Equipment Repair Order (ERO):

When a broken piece of equipment, whether a principal end item (PEI), such as an Amphibious Assault Vehicle (AAV) or a secondary repairable, such as an AAV transmission, is inducted into the shop, an Equipment Repair Order (ERO) is initiated in the Marine Corps Integrated Maintenance Management System (MIMMS).

The ERO is a computerized tracking form for all the actions done on this piece of equipment in a particular shop floor, including tracking time spent in each phase of repair – inspection, awaiting shop space or parts, etc., defects noted and man-hours expended, and parts requisitioned and the status quo of those requirements. Typically, complex repairs require one or more repairs parts to replace the failed or degraded equipment. Each repair action associated with an ERO will have a "layette" or separate parts bin, where requisitioned parts are assembled and staged as, they arrive. When all the parts required for this particular equipment have been received, the layette parts are moved to the bench or bay where the broken equipment is located and the repair action comes into effect.

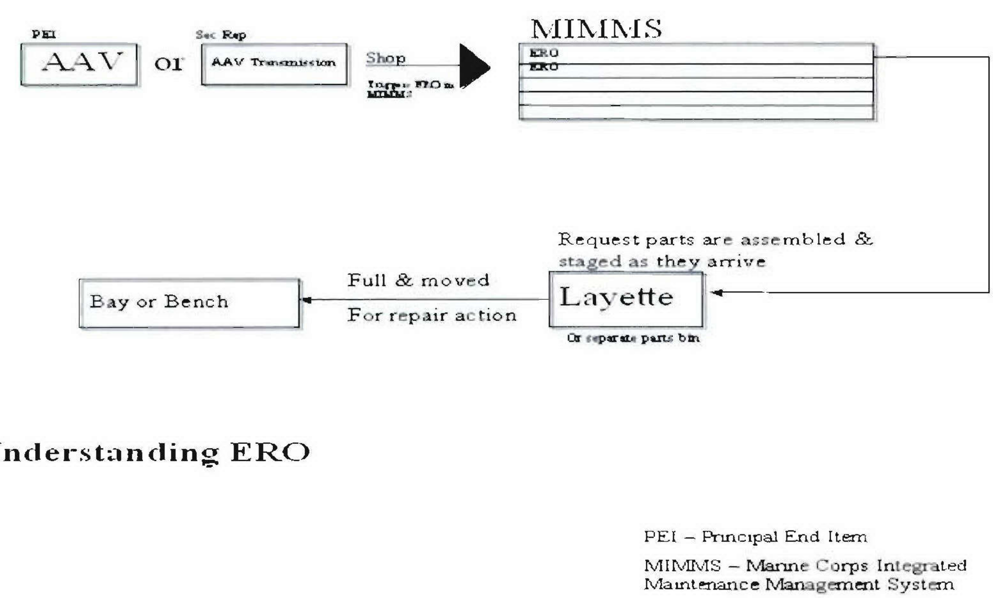

Figure 3.4: Understanding ERO

3.3.3.3 Supply:

Each unit performing maintenance keep small amounts of fast moving stock such as bolts and fasteners in their Pre-expended bins (PEB).

For a more substantial part, a unit however has to go to the Intermediate level of supply for the MEF, maintained by the supply battalion resident in the MEF.

The supply battalion is the main provider of stocks for the entire MEF. It divides its inventory into two parts:

i) Consumables, held by General Account
ii) Repairables, held at the Repairable Issue Point (RIP)

These supplies are maintained and controlled by SASSY Management Unit, or SMU (SASSY stands for Supported Activities Supply System, the information system used to manage stocks). The supply battalions disperse many inventories all under the single control of SMU.

3.3.3.4 How units request parts?

- Units requisition parts by placing orders through their local Asset Tracking for Logistics and Supply System (ATLASS) computer, either through e-mail or with daily submission of computer diskettes to the SMU.
- The SMU processes all requests in batch mode once daily (through an offsite mainframe computer), producing material releasing order (MRO) the next morning, for picking, packing, and shipping to the requisitioner.
- Items the SMU does not stock or currently lacking may be sent by the SMU to the wholesale level of supply.
- SMU *consumables* accounts can be replenished from wholesale supply maintained by the Defense Logistics Agency (DLA) or by providers certified by DLA (e.g., through the Prime Vendor or Virtual Prime Vendor initiatives).

Repairable stocks can be replenished by similar sources or from the output of the General Support Maintenance Company (4th echelon).

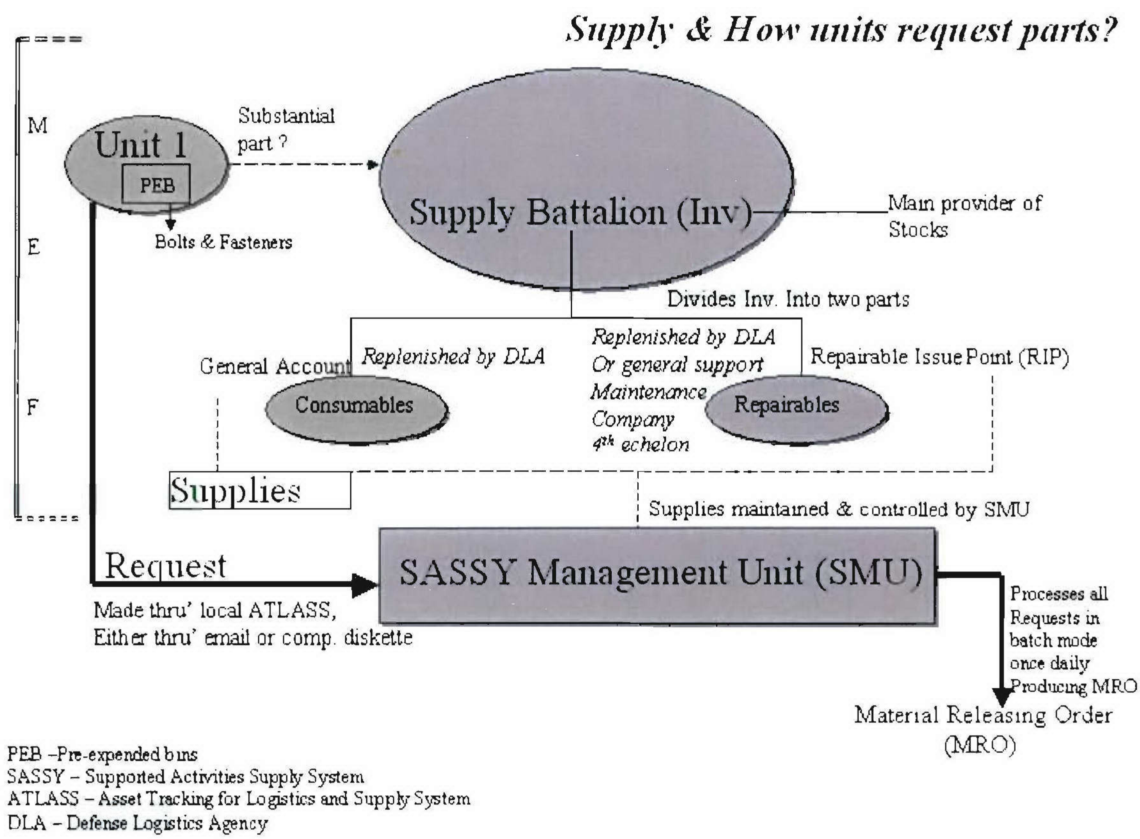

Figure 3.5: Supply and how units request work?

3.3.4 Maintenance Systems used in USMC

This section summarizes document [17], which will help us to understand functionalities in MIMMS, flow of information, maintenance orders, its interfaces etc.

3.3.4.1 Marine Corps Integrated Maintenance Management System (MIMMS)

I. Maintenance Management:

Within the area of maintenance management, there are eight sub functional areas. They are as follows:

- Maintenance Administration
- Personnel and Training
- Records and reports
- Publication control
- Equipment Availability
- Preventive Maintenance checks and services (PMCS) and corrective maintenance

- Supply support and maintenance related programs

a) Equipment Repair Order (ERO):

- It is a device within the unit's organic maintenance capability, which is used for request modification, calibration, corrective maintenance, preventive maintenance checks and services and technical inspections on all ground equipment
- Can also be used to transfer work to higher echelons of maintenance and for recording and reporting all maintenance that has been performed.

b) Equipment Repair Order Shopping/Transaction List (EROSL): It has two purposes

- First: request repair parts associated with the ERO.
- Second: To input MIMMS data into the system, either automated or manual.

c) Equipment Records: There are many records but the two most predominant ones are: preventive maintenance checks and services (PMCS) records and corrective maintenance (CM) records.

- PMCS record ensures that the PM is systematically scheduled and recorded when complete
- CM record ensures that a history is established for the piece of ground equipment that requires to be maintained.

d) Calibration control Program:

- It ensures that all Test, Measurement and Diagnostic Equipment (TMDE) is calibrated within certain range of scale.

e) Tool Control:

- Ensures accountability of all tools in stand-alone sets, chests or kits and or if they belong to a PEI.

f) Product Quality Deficiency Report (PQDR):

- Provides information to activities responsible for development, procurement, or management of equipment concerning deficiencies in material, design, or procurement
- It enables the activities to initiate action to correct the reported deficiency.

g) Modification Control: This program gives the equipment owner the means of accurately determining the modification status on assigned equipment. There are two types of modification: Urgent and Normal.

- Normal: modification lend themselves to acceptance scheduling usually within one year
- Urgent: modification require that the equipment be dead lined or sharply curtailed until the modification is applied.

h) Publication Libraries: The publications fall into two categories:

- Technical (Marine Corps Orders, Bulletins, etc.)
- Non-technical (Technical Manuals, Stock Listings, Modification Instructions, etc.).

II. Support Supply:

Within the support supply, there are six sub functional areas. They are as follows:

- Pre-expended Bins
- ERO parts usage
- Repair parts usage
- New equipment
- Maintenance and supply validation
- Maintenance and supply reconciliation

a) Pre-expended Bin (PEB):

- For mechanics and technicians performing quick repairs within the maintenance facility, it provides continuous availability of low-cost, fast moving items.

b) ERO Parts Bin:

- It is an area secure against pilferage and organizes repair parts waiting to be installed on equipment until the mechanic or technician requests them for installation
- Repair parts held in the bin may either be new or used repair parts and all repair parts must be signed for upon removal from the repair part bin.

c) Repair parts usage:

- All repaired parts must either be applied to a piece of equipment or 'rolled back' to the supply system for another unit to use
- The aforementioned is based on receipts, cancellations, and parts applied.

d) New Equipment:

- All new equipment will have a fielding plan and will give detailed instructions on placing the new equipment into service
- Currently User Logistics Support Summary (ULSS) is used to accomplish this.

e) Maintenance and Supply Validation:

- MIMMS Clerk will **validate the existence or non-existence of all repairs**, repair parts, status quo and conditions of equipment and items that are in the maintenance cycle
- It is accomplished using Daily Transaction Listing (DTL)

f) Maintenance and Supply Reconciliation:

- Not only the validation of the repair parts are done but also have to reconcile with the unit supply section to ensure that all pending actions between supply and the maintenance section are accomplished or not

III. MIMMS-AIS:

Within MIMMS-AIS, there are two sub functional areas and are as follows:

- MIMMS/ Marine Corps Ground Equipment Resources Report (MCGERR)
- MIMMS input and output reports

a) MIMMS and Marine Corps Ground Equipment Resources Report (MCGERR):

- It is a computer oriented command information system designed to provide information on ground equipment readiness of Marine Corps unit
- **Readiness** relates to the ability of a certain piece of equipment (or unit) to accomplish a certain task which is specifically designed to achieve

b) Input and Output of MIMMS and MCGERR:

- Maintenance Management specialist will take the raw data and actually keypunch it into the AIS and ensure that the data was properly received by MISCO (Maintenance Information System Coordination Office)
- This information will enable to 'pull' certain type of information out of the system by means of an automated retrieval system

IV. MISCO:

There are four sub functional areas and are as follows:

- Monitor the operation of MIMMS/MCGERR
- Supporting the customer
- Resources
- Production

a) Monitor the operation of MIMMS/MCGERR:

- To ensure that the MIMMS program is updated with all the current changes that are received from the Regional Automated Service Center (RASC)
- Maintenance Management personal uses MIMMS to input the data into the automated system whereas, the supply support personnel use the Supported Activities Supply Support System (SASSY) and Asset Tracking Logistics Automated Support System (ATLASS) to input their information and follow on with the requirements
- Both these systems must interface on a systematic basis in order to 'feed' each other with updates.

b) Supporting the customer:

- It consists of activities such as, answering questions, inputting data, and giving guidance in the MIMMS field
- Maintenance management personnel must be proficient to analyze the data and make recommendations for the unit

c) Resources:

- Equipment cannot be repaired without the mechanic's time, equipment time, and manager's time
- Basic tools that are used to repair parts are: repair parts, tools and publications
- Funding

d) Production:

- Maintenance production is concerned with the actual repair of equipment that includes calibration, modification, corrective maintenance (CM), and preventive maintenance (PM)
- It also considers overhaul, rebuild, conversion, and modernization of equipment.

V. Commodity Sections:

- Common commodities that are found in the battalion/squadron are: Motor transport, Engineer, communications, and ordnance.
- Commodity managers, supply officer, and maintenance management officer (MMO) are special staff officers who fall under the cognizance of S-4
- The maintenance management personnel serve as a liaisons between supply/maintenance commodity shops and the S-4 Officer to ensure rapid maintenance turn around and accurate readiness reporting

VI. Maintenance Management Standard Operating Procedures (MMSOP):
All ground units are required to have a set procedure to follow on a systematic basis and can be either written by the unit or use higher headquarters MMSOP. The following are the two procedures:

- Desktop Procedures (DTP): Frequent change of personnel within the units result in a lack of expertise and will interrupt the day-to-day operations. DTP assists and improve the overall efficiency of an organization.
- Turnover Folders (TOF): They are like the DTP but goes into greater detail for the maintenance manager.

3.4 Concept of Autonomic Logistics (AL) on LAV

3.4.1 Focus LAV from JSF perspective

Our study will focus on how maintenance (using prognosis and diagnosis) information from a principal end item (PEI), such as a Light Armored Vehicle (LAV) is distributed to the concerned personnel for replenishment. With this notion as our basis, the scope of our project will consider the AL concept to be the end-to-end information distribution flow.

We have used some of the basic foundations of JSF in building the focus for LAV overall AL [Appendix: 3]. The four significant features of the AL concept to provide a futuristic logistics support for the platform LAV are as follows:

1. Preventive Maintenance and Health Monitoring
2. Shared Data Environment (SHADE)
3. Technologically Enabled Maintainer
4. Operational Architecture for Advanced Logistics Infrastructure

<u>Preventive and Health Management:</u>

Sensors placed on the critical parts in a LAV transmit status data to a unit personal who/which will convert this data into information for a specific subsystem. The unit personal might be a software module, monitoring system and/or man-in-the-loop, which fuse the information obtained from various sources by means of data fusion, reasoning, and anomalies. This information will determine whether the part or component of a specific subsystem exhibit certain characteristic that may lead to part failure.

Information collected by the unit personal will then be transmitted to a unit commander for further information fusion and to eliminate ambiguities. Data fusion will enable the system to avoid false alarms by cross checking the anomalies with information obtained from other subsystems.

The unit commander filters information and sends certain information to the LAV operator and the remaining information to the maintenance personnel for action. Data fusion will enable the system to avoid false alarms by cross checking the anomalies with information obtained from other subsystems. Sensor information will be validated at the unit personal and commander level.

Other aspect will be the prognostic calculation, which will aid in calculating the remaining useful life of a specific component in a subsystem. This information together with the rest of the information from the unit commander is transmitted to SHADE, which will trigger or inform the logistics supply what it has to do to maintain the LAV fully operational.

In other words, prognosis in a LAV will estimate the remaining useful life of a component and allow a lead-time for the logistics pipeline to get parts and to educate the maintainer to change the respective parts.

Shared Data Environment (SHADE):
The significant element of AL will be the SHADE. It will serve as an interface that would take the information from the unit commander and transmit to all the other necessary maintenance management, logistics, supply, mission planning etc. Some tasks that will be performed either automatically or integrated with SHADE are as follows:

- Mission planning
- Maintenance action scheduling and training
- Ordering of spare parts
- Storing maintenance, training, spare parts, and logistic information in the database warehouse

The aforementioned automated tasks will include a man-in-the-loop with certain authority to access the system and make necessary changes.

In other words, the information from the prognostics and health management system will allow the SHADE to trigger relevant actions and recommendations.

Technologically Enabled Maintainer:
Maintainer in the AL concept will have a sound knowledge in modern and technologically capable tools to act efficiently when called for immediate maintenance. The tools include: comprehensive knowledge of the platform before the maintainer begins work, real time guidance to provide supplementary information when required, and timings to conduct the specific task.

Advanced Logistics Infrastructure:
If the logistics infrastructure does not provide the right part at the right time at the right place then the above mentioned two systems would be of no avail. To have an adaptive Logistics infrastructure, the MC logistics enterprise is currently working on with the Operational Architecture [Appendix 1]. This architecture captures the information flow between supported unit, supporting unit and the enterprise level.

In brief, the information from Preventive and Health Management system will trigger the advanced logistics infrastructure through SHADE and will assign the maintainer to fulfill the maintenance action so that the LAV platform is fully operational during its mission. The LAV AL will be enabled with both the COTS and GOTS software. We show in Figure 3.6 our conceptual view of LAV AL.

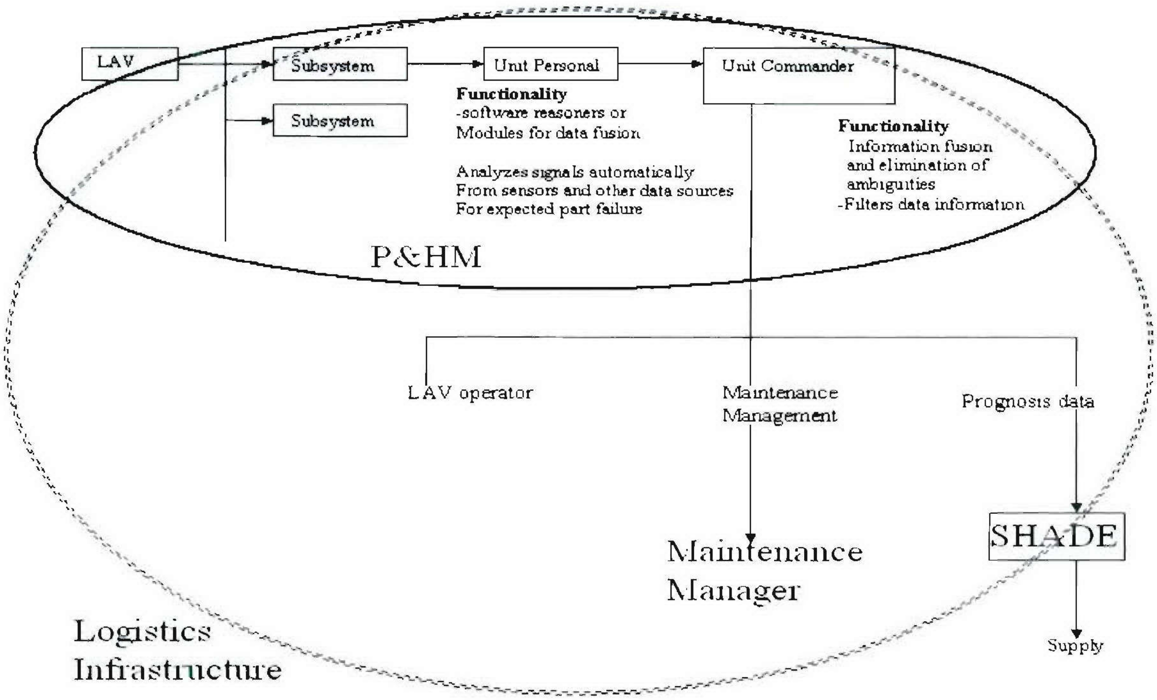

Figure 3.6: Conceptual view of LAV AL

3.4.2 Work Break down Structure (WBS) for LAV – 25

In order to have a fully functional Preventive and Health Monitoring system in a LAV, we first have to study the LAV features and analyze its critical parts. After identifying the critical parts, different types of sensors will be placed on it to collect prognosis/diagnosis data from the platform.

To achieve the above goal, we have to thoroughly understand the WBS of a LAV. With the information obtained from Maj. Landry, we came up with a first cut WBS as shown in Figure 3.7.

Our present work is focused on extracting relevant part information by analysis [Refer Chapter No. 6] from the Quad Model data set sent by Maj. Landry. This information will later be linked to WBS, which will hence outline the next level or subsystem for the WBS.

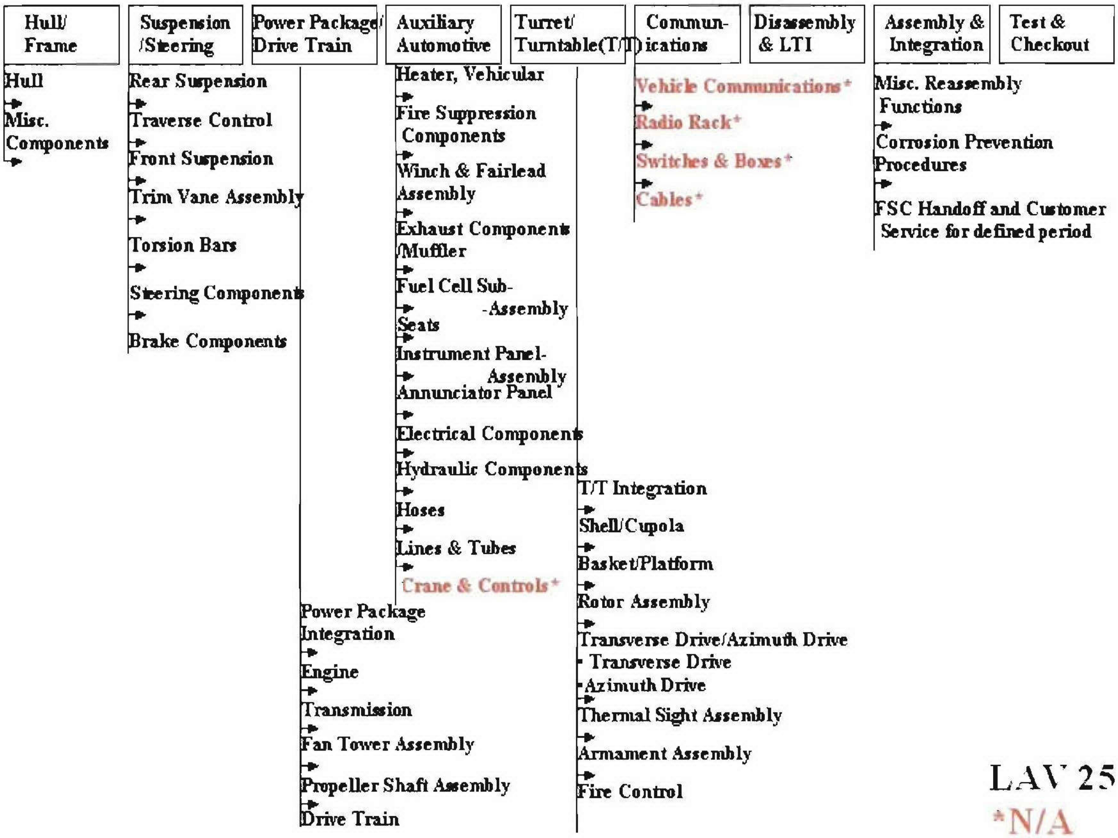

Figure 3.7: WBS for LAV 25

4 Maintenance Activities

In an attempt to answer some of the questions posed in previous sections regarding how maintenance data can be generated & processed autonomously and further distributed for triggering specific functions within the logistics chain, the literature related to Sensor Processing, Condition Based Maintenance (CBM) in the Army, Maintenance in Aviation Industry, Industrial Logisitcs Applications: Penske Case, Maintenance and Automotive Telematics – GM Onstar Case study were reviewed. Each of these studies revealed varied aspects of maintenance that are suggestive of solution methodologies for the integrated diagnostics of ground equipment.

4.1 Sensor Processing

In the process of applying diagnostics to a specific subsystem within the LAV the characteristics of the subsystems have to be analyzed along two perspectives. The first being the criticality of the sub-system, this questions whether or not to use diagnostics module to monitor the condition of a specific subsystem. The second perspective questions what types of sensors are commercially available and what sensor processing techniques can be used to diagnose the selected subsystem. Appendix: 4 serves the purpose of aggregating information about commercially available sensors and different sensor processing techniques that are potential candidates for application to CBM.

The sensors are grouped as mechanical sensors, electrical sensors and communication sensors. The study reviews a wide spectrum of sensors – transducers, classical integrated sensors and smart sensors. The signal processing literature entails signal conditioning and processing. The literature also gives a high level description of the methodology by which the sensors can be used for diagnostics within an LAV. It further describes the different analysis techniques that can be used to make relevant inference regarding the condition of the subsystem from the corresponding signal data.

4.2 Condition Based Maintenance (CBM) in the Army

CBM is defined as a set of actions taken as a consequence of knowing the current operating status of the equipment. These would include maintenance scheduling, sourcing parts for replacement and making orders for replenishment to maintain a certain level of inventory. Determining current equipment operating status can be accomplished in three basic ways:

- By using sensors and computers that are embedded into the operating equipment and monitored on-the-fly,

- By applying portable sensing equipment that tie up to an interface or wiring harness to "read" embedded sensors, or to apply the sensor itself, such as a stand-alone wear measurement,
- By using manual gauges or instruments, such as a tire-wear gauge

The intent of CBM is to perform maintenance only when there is objective evidence of need. The technical capability of CBM is to identify current equipment conditions. Acting upon these condition indicators is more than a matter of being able to schedule maintenance or forecast failure. Once the objective evidence of need is in hand, forecasting or scheduling maintenance tasks can be performed. The army is currently working on CBM programs within three specific time frames. In the short term, the focus is on immediate technology insertion to enhance diagnostics. In the near future, the goal is to develop anticipatory maintenance capabilities within the ground equipment and in the long run, it aims to develop a proof of concept for embedded diagnostics for a common architecture and approach. The review conducted on the ongoing CBM projects within the army reveals the wide variety of sensors that are used for condition monitoring. The conceptual ideas of the rule based systems that facilitate transformation of the sensor or model data into meaningful inference have been captured within the literature. The overarching concept of autonomic logistics that has been the guiding framework for equipment maintenance within the army can be imbibed and tailored to suit the maintenance processes for ground equipment within the USMC. A detailed description of ongoing CBM programs within the army is provided in Appendix 5.

4.3 Maintenance in Aviation Industry

An important task is to identify the critical components within the LAV that would prove ideal candidates for diagnostics. In the aviation industry, maintainability of the machinery is a key factor and is considered right from the design stage. The criticality of the machinery within the commercial aircrafts have been identified and condition based monitoring is being used so as to conduct diagnostics while the aircraft is in use. This enables the maintenance action to be taken on time and prevent failures. The technology used for monitoring aircraft engines has greatly improved over the years with the use of high fidelity sensors. The main breakthrough in this field is the development of a central maintenance computer that acquires and processes data from an entire fleet of aircrafts when they are in use. The on-board processing unit interprets the signal data and transmits the coded information to the central maintenance computer via satellite based aircraft communication and addressing system (ACARS). This data is then distributed to other bases if needed. A web-based portal provides real time information regarding the status of all the aircrafts within the fleet. Thus, the decision makers can find the needed information any time – anywhere. Logic diagrams have been generated for performing maintenance activities. The schema provides a sequential set of directions for accomplishing the maintenance task by following the logic diagram.

For detailed information on Aviation Industry Maintenance (Boeing), refer Appendix: 6.

4.4 Industrial Logistics Applications: Penske case

Penske, one the country's largest logistics companies, has a large fleet of vehicles. The maintenance processes practiced within the organization reflect some of the best practices within the commercial sector. Reviewing this information could prove as a good reference for maintenance process improvement within the USMC. The essence of the maintenance process followed ate Penske includes capturing the performance data of specific systems such as engines, fluids, parts, tires etc. Every maintenance transaction on each vehicle is also captured. This data forms the basis for analysis and indicates the defect levels of the systems. The current equipment status is translated into corrective feedback and distributed to Penske technicians as well as designers for the next generation vehicles. A brief description of the joint studies done by Penske partnering with Ford, Mission Foods and Whirlpool are included in the Appendix: 7.

4.5 Maintenance and Automotive Telematics – GM Onstar Case study

A critical review of the telematics literature presents the use of condition monitoring within an automobile. The emphasis in the literature is on available technologies for communication and location based services, it does not explore in depth the sensor based techniques for diagnostics but helps comprehend in a generic fashion the data acquisition and communication process. The telematics enabled vehicle essentially is capable of two-way communication, location identification and has a control unit that is interfaced with the vehicle's electronic systems.

The telematics control unit is an embedded computer designed for telematics functions. The user interface uses audio capabilities within the auto and has a display unit as well. The control unit essentially has limited capabilities and is supported by a remote server. This reduces manufacturing costs as well as minimizes technology obsolescence. The human machine interface exploits the audio capabilities available within the vehicle. Speech recognition systems are currently used in automobiles for the command input. Large display units could prove a major distraction to the driver and so text-to-speech output via the audio is the current state-of-the-art. Emerging technologies in the areas of software platforms that are more flexible and communication technologies which use cellular and satellite networking will greatly enhance the performance of telematics systems. High bandwidth Wireless local area networks co-existing with blue tooth technologies will facilitate the automobiles to communicate with each other and other local systems and thus increase the support available to the vehicles.

Though the operating conditions vary vastly in a combat environment the technologies that are currently being used and have been identified as the future enhancers for automotive telematics, are relevant to the IDGE study. The conceptual description of the telematics techniques and the case study on GM Onstar detailed in the Appendix: 8 could provide the right direction towards realizing a framework for integrated diagnostics of the ground equipment. It also helps identify the current state-of-the-art technologies in remote diagnostics and the future technologies that could enhance the same.

5 Use Cases as a Mechanism for Envisioning the IDGE System

5.1 What Are Use Cases?

Use Cases are a technique that allows modeling *what* an envisioned system will do. With use cases, the analysis can be performed at a level that is easily accessible to the potential users. It also allows the system architects and future designers the opportunity to scope the project and gives the project some structure. A Use Case, thus, represents a unit of analysis that can progress to becoming a unit of effort estimation, and the smallest unit of delivery, testing and deployment. An important ancillary benefit of use cases, therefore, is that they can be developed in an iterative and incremental manner for eliciting requirements, developing, implementing and deployment. As a user-centered analysis technique, the purpose of a use case is to capture a scenario that would yield a result of measurable value to an actor. A use case may involve multiple actors, but only a single actor initiates the use case. Because actors are beyond the scope of the system, use-case modeling ignores direct interactions between actors.

The term use case was introduced by Ivar Jacobson et al. [14]. A use case is a description of a cohesive set of possible interactions that an individual actor will carry out with a system. An actor is a role played by a user (i.e., an external entity that interacts directly with the system). A use case is thus a general way of using some part of the functionality of a system.

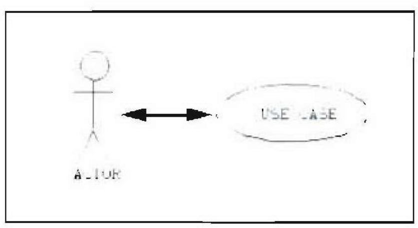

Figure 5.1: Primary Use Case Notations

A use case defines a goal-oriented set of interactions between external actors and the system under consideration. Actors are parties outside the system that interact with the system. An actor may be a class of users, roles users can play, or other systems. The system is treated as a "black box", and the interactions with system, including system responses, are as perceived from outside the system. Thus, use cases capture who (actor) does what (interaction) with the system, for what purpose (goal), without dealing with system internals. A complete set of use cases specifies all the different ways to use the system, and therefore defines all behavior required of the system, bounding the scope of the system.

A use case is, thus, not a single instance of a scenario but rather a 'class' that specifies a set of related usage scenarios, each of which captures a specific course of interactions that take place between one or more actors and the system. The description of an individual use case typically can be divided into a basic course and zero or more alternative courses. The basic course of a use case is the most common or important sequence of transactions that satisfy the use case. The basic course is therefore always developed first. The alternative courses are variants of the basic course and are often used to identify error handling. Within reason, the more alternative courses identified and described, the more complete the description of the use case and the more robust the resulting system.

Use Cases are not a functional decomposition model. They do not capture *how* the system will do something. That is the domain of developers. They do provide a vehicle for communicating with the developers by identifying scenarios of value to the users, and provide a tool for envisioning and architecting that can be used to communicate with both, the system developers and system users. Keeping these objectives in mind, generally, use case steps are written in an easy-to-understand structured narrative using the vocabulary of the domain. This is engaging for users who can easily follow and validate the use cases, and the accessibility encourages users to be actively involved in defining the requirements. The set of all use case descriptions, thus, specifies the complete functionality of the system.

5.2 Why and How Use Cases can be used to Envision IDGE?

For an open-ended problem such as the proposed IDGE initiative, use cases represent an indispensable tool precisely because of its vague, ill-structured, futuristic focus. The myriad of actors involved in the system need to make their perspectives clear. The research team needs a technique that they can use to understand and envision the envisioned IDGE effort in terms of meaningful chunks. These requirements make use cases the appropriate choice for envisioning IDGE. With the use cases, IDGE also inherits a rich stream of research and a strategy that the research team can follow to track progress, and integrate various elements. A simple statement of this strategy is shown below.

1. Define the problem informally in the domain of interest
2. Develop an informal strategy for the domain of interest
3. Formalize the strategy as use case chunks
4. Use the use cases to identify information of interest
5. Clarify specifications

It is the very simplicity of use cases that makes them so powerful. The steps can iterate a number of times as the outcomes of each inform the next step as well as the overall process. The steps are instantiated for the IDGE below.

1. First, the problem can be defined informally to start the process. In the case of the IDGE system, this can be articulated as application of the autonomic

logistics concept for ground equipment to ensure better maintenance of ground equipment.

2. Second, an informal strategy can be developed for the domain of interest. In case of IDGE, this involved choosing the LAV as an exemplar to make the discussions concrete, and scoping the discussion by the OA processes (on the top-side) and the sensor architectures (on the bottom-side).

3. Third, the strategy can be formalized as use case chunks. Identification of use cases thus requires chunking the functionality of the envisioned system into cognitively and pragmatically manageable units. For the IDGE, this means understanding different roles (actors) and how they will interact with the proposed system at different times and to achieve different goals.

4. Fourth, the use cases can be used in a manner that directly addresses concerns of interest. For the IDGE, the immediate concerns of interest are the data implications and the universal data requirements. These can be tagged to the use case descriptions to identify the data implications of each use case.

5. Finally, the specifications can be formalized to the extent possible so the process can repeat.

An example set of use cases [15] clarifies how use cases may be written in the first pass through this strategy. The envisioned use cases for Door Master, a security system for controlling entry of employees through a secured door can be captured by use cases that include the following.

a. Enter the Disabled Door. Employees and security guards enter freely through the door when Door Master is disabled.
b. Enter the Secured Door. Employees and security guards enter through the door by entering the entry code on the numeric keypad, entering through the door, and closing the door behind them.
c. Change the Entry Code. Security guards change the entry code by pressing the change entry code button on the control panel, providing authorization by entering the security code on the numeric keypad, entering the new entry code on the numeric keypad, and verifying the new entry code by reentering it on the numeric keypad.
d. Change the Security Code. Security guards change the security code by pressing the change security code button on the control panel, providing authorization by entering the old security code on the numeric keypad, entering the new security code on the numeric keypad, and verifying the new security code by reentering it on the numeric keypad.
e. Enable the Door Master. Security guards enable Door Master by pressing the enable button on the control panel and providing authorization by entering the security code on the numeric keypad. Door master then turns off the disabled light, turns on the enabled light, and locks the door.

f. Disable the Door Master. Security guards disable Door Master by pressing the disable button on the control panel and providing authorization by entering the security code on the numeric keypad. Door master then turns off the enabled light, turns on the disabled light, and unlocks the door.
g. Enter the Entry Code. Employees and security guards enter the entry code by pressing five keys on the numeric keypad followed by the enter key. Door master beeps after each key and verifies the entry code.
h. Enter the Security Code. Employees and security guards enter the entry code by pressing seven keys on the numeric keypad followed by the enter key. Door master beeps after each key and verifies the entry code.
i. Raise the Alarm. The alarm is raised if the door is left open too long or if the door is not shut when Door Master is enabled. The security guards disable the alarm by entering the security code.

6 Data Mining for Maintenance Design and Analysis

6.1 Introduction

The quadrant model is a classification tool that can be used to classify the elements along two distinctly different attributes. Relevant to this study these attributes are mission value and risk/uniqueness. The main computation that has to be performed is to quantify risk and mission value associated with the different components. The generic quadrant model that can be used has the X-axis representing the mission value of a particular component and the Y-axis representing the risk/uniqueness associated with the components. The value increases from *low* to *high* as we traverse from left to right along the X-axis and the risk increases from *low* to *high* as we traverse *bottom up* along the Y-axis. This method of classification would essentially help identify the critical components within the structure of the LAV. Once this is achieved, the critical component can be used as an ideal case study for using condition based maintenance and further developing the information flows that can be autonomously aggregated to form the inputs to the ERP system.

Historical data, such as frequency of failures, mean time between failures, repair cost, inventory levels, fill rate and other data inputs can be used for mining and identifying patterns which will form important inputs to the decision support systems – for the tactical, operational and strategic level. The first step towards achieving this goal would be to acquire as much historical data as available within the operational units of the USMC.

- Qualitative attributes have to be translated to computable quantities.
- Attributes –
  - Risk involved in acquiring the component for replacement.
  - Value of the component to the accomplishment of the mission.

The quadrant model has two 'dividers' that partition the diagram into four distinct quadrants. They are categorized as Routine, Leveraged, Bottleneck and Critical. Each of the quadrants represents components with distinct levels of risk and mission value. The dividers can be adjusted to change the fraction of components falling into the four categories. The diagram given below gives the quadrant model with a sample of the attributes that ascertain the belonging of the components to the respective quadrants.

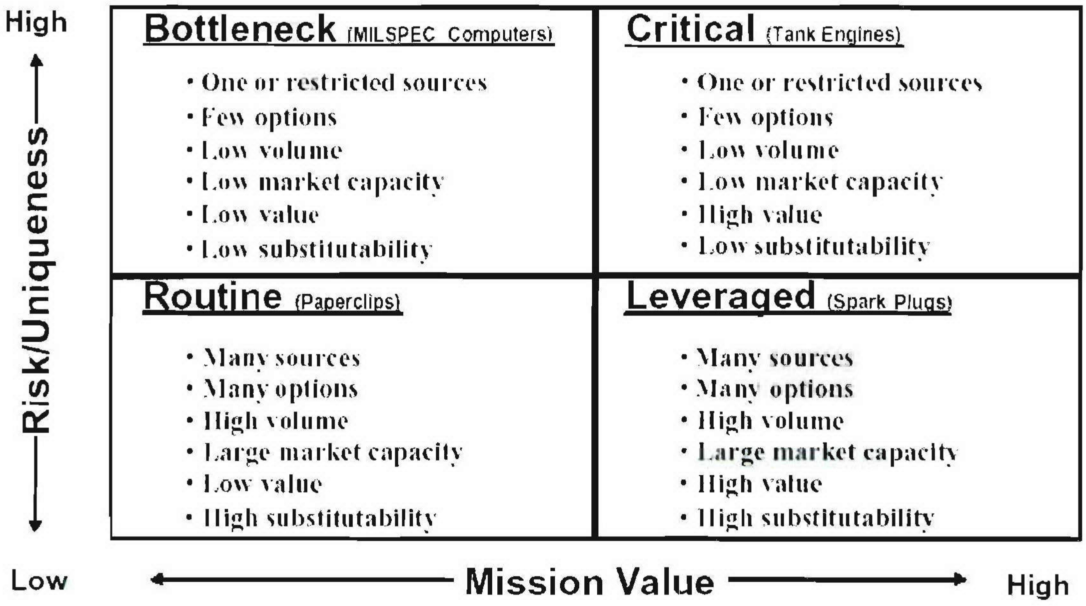

Figure 6.1: Quadrant model showing the attributes & a sample of the various criteria that determine the belonging of each component to the respective quadrants.

6.1.1 Available information

The data that is currently available for preliminary analysis has been obtained from historical data. Some of the attributes that have been specified within the quadrant model data for SECREPS use acronyms. The team has posted questions regarding these acronyms and the type of simulation models that have been used in the data analysis. Though the current understanding of the data worksheet made available by the USMC is limited, the worksheets have been used to categorize the different components into the different quadrants as a first cut to the analysis. The data specified below have been used for the analysis.

- Data on 108 subsystems identified by the National Stock number and the NIINS
- The repair costs associated with each of these subsystems.
- The unit price for the different components.
- Demand for the components simulated using historical data.
- Number of items of each type that are stocked.

Using this information, the following criteria that will aptly describe the risk and mission value associated with the components were identified.

- Difference in demand and number of components stocked (deficit).
- Cost incurred as a share of the total budget.
- The ratio of the repair cost to the component cost.
- The ratio of demand for a component to the total demand for components.
- Ratio of the demand for a particular component to the number stocked.

- Frequency of breakdown (1999-2001)

The idea of criticality or risk associated with a particular component is determined by the perspective or view along which the analysis is carried out. For instance the same component would prove very critical to the finance management owing to the high cost of repair or replacement, while it may not be equally critical to maintenance management owing to its very low frequency of failure. Thus the goal of effectively classifying the components demands using various perspectives and working on the relevant criteria for classification. The criteria for classification have to be understood by exploring the requirements of the users at the different levels. This information has to be generated by identifying the users and obtaining answers to specific questions through interviews and/or questionnaires.

An example illustrating the relevance of the perspective for classification is given below –

Supply perspective: Viewing the information from a supply perspective would reveal that the main criteria that have to be considered are – the inventory levels of the different components, customer waiting time, demand during lead time, fill rates etc.

Monetary perspective: The criteria for classification while reviewing the monetary implications of the maintenance of different components would be as follows – Unit cost of the component, Repair costs, Transportation costs and overall inventory costs incurred for stocking specific amounts of each component.

Training of maintenance personnel: The frequency of failures would play an important role in developing relevant maintenance expertise for the mechanics who will be deployed within the tactical and support units. It is logically evident that enabling greater number of mechanics, through appropriate training, to perform maintenance activities on frequently failing subsystems will improve the efficiency of operations.

Maintenance support systems design: The necessity of a system offering remote maintenance support to the mechanic performing maintenance on a particular component will require large volumes of data to be stored and transmitted in real-time. Owing to the limitations in communication infrastructure it is important to choose those subsystems to which such a support is critical. This can again be achieved by classifying the components based on the time required for maintenance operation, ease of problem identification and localization.

The above perspectives are just a representative collection of the different perspectives along which the components can be classified. The list is definitely not exhaustive and many more views will be added after ascertaining the requirements of the users who would be interacting with the information system. The final goal of using the quadrant model to develop a robust classification schema for varied uses has been initiated through this analysis.

6.2 DATA ANALYSIS

6.3 Quadrant Model for the LAV-25 (E0947) SECREPS

The quadrant model used by the USMC categorizes (classify) the LAV-25 SECREPS (Secondary Repairables) inventories so that the effectiveness of procurement/contracting, acquisition logistics, and material management can be improved. From the analysis of sample data of their practice study (E0947 SECREPS Quad Acq.xls), it is found that variable mission value and risk/uniqueness related information for the each LAV-25 SECREPS part are considered to build two-by-two matrix with 4 different cells, namely Bottleneck, Routine, Leveraged, and Critical. After building the matrix, the 4 cells are divided with two dividers, one is the divider for the mission value (X-divider), the other is the divider for the risk / uniqueness (Y-divider). From the current analysis, it is found that the decision making for these two dividers is dependent on their budget constraint. Figure 6.2 shows the LAV-25 SECREPS quadrant model.

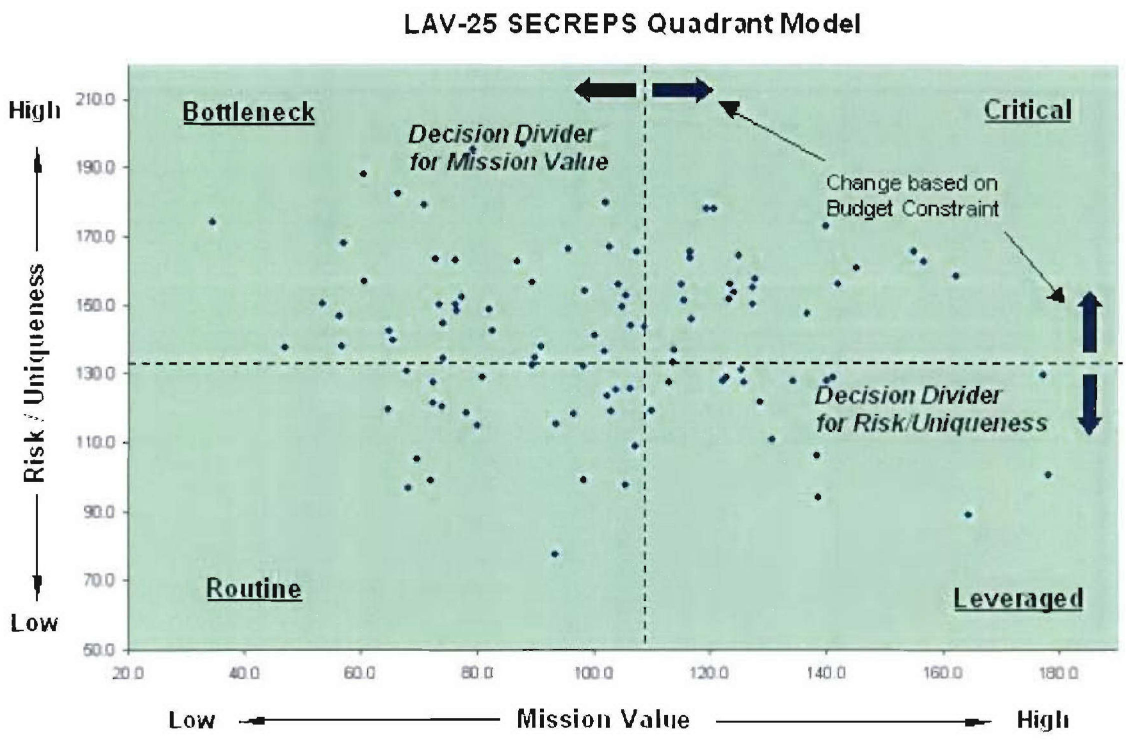

Figure 6.2: LAV-25 SECREPS Quadrant Model

6.4 ABC Analysis for the LAV-25 (E0947) SECREPS

ABC analysis, sometimes referred as Pareto analysis, is a method of classifying items, events, or activities according to their relative importance. It is frequently

used in inventory management where it is used to classify items into groups based on the total annual expenditure of each item.

For the maintenance of the LAV, organizations should concentrate on the high value and important SECREPS (Secondary Repairables) for the LAV.

6.5 Study of ABC Analysis for the LAV-25 (E0947) SECREPS

First Step: Identify criteria, which make a significant level of control important for any SECREP part. In this analysis, since most of data fields in 'E0947 SECREPS Quad Acq.xls' are not clearly defined at this moment, two possible factors for this analysis can be the 'average annual demand' and 'cost' for each repairable part.

NIIN	Nomenclature	Annual Demand	Unit Rcost	Annual Requirement Value (ARV)	Cmul_ARV
14304339	SENSOR UNIT,LASER DETECTING	7.40	60654.10	449107.93	449107.93
14427645	ENGINE,DIESEL	7.40	28205.69	208846.54	657954.47
11516429	CONTROL DISPLAY UNIT	29.23	4602.12	134510.57	792465.04
219063912	DIFFERENTIAL,DRIVING AXLE	18.32	6218.00	113889.96	906355.00
11642599	DISTRIBUTION BOX	7.79	11508.66	89699.88	996054.88
11660375	HAND STATION ASSEMB	6.24	13933.55	86879.79	1082934.67
⋮	⋮	⋮	⋮	⋮	⋮

Table 6.1: Annual Requirement Value Table

Second Step: These two factors can be multiplied to give the annual requirement value (ARV) – the total value of annual usage. If the items are then listed in descending order of ARV, shown at above table, the most important repairable parts will appear at the top of the list. If the cumulative ARV is then plotted against the SECREPS parts then a Pareto curve will be obtained. This ABC analysis graph is shown in the next figure.

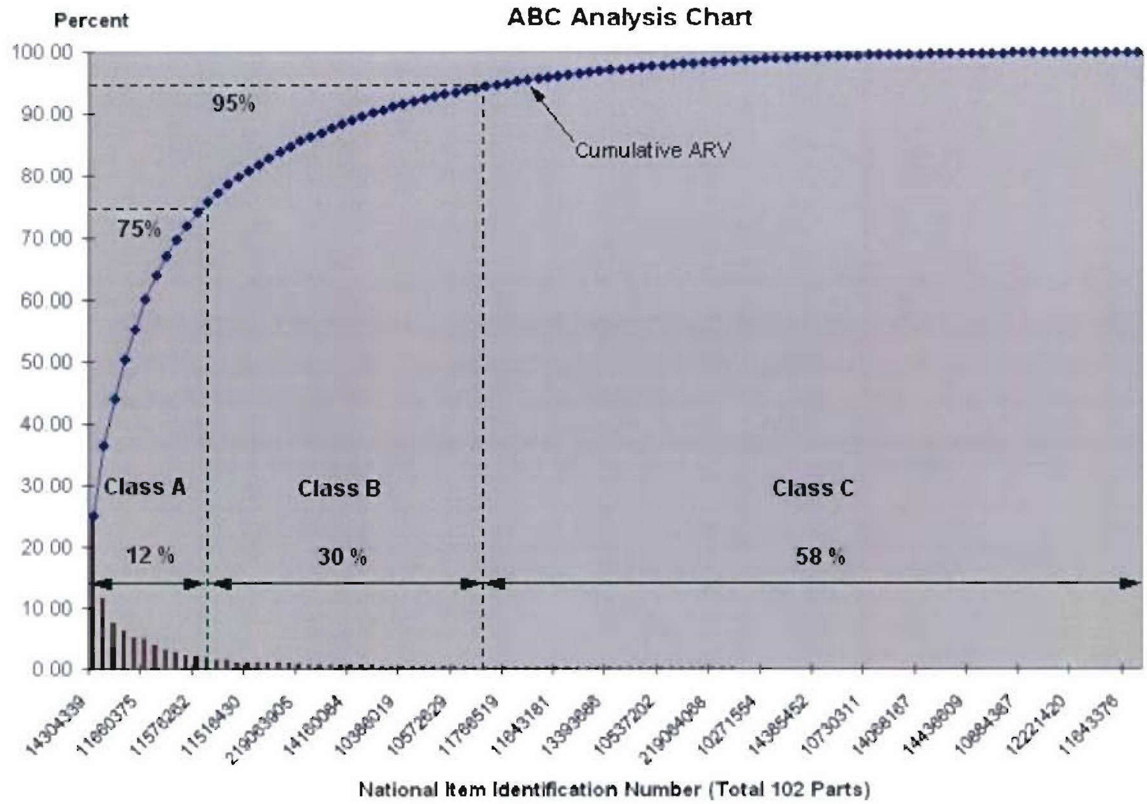

Figure 6.3: ABC Analysis Graph

Class	NIIN	Nomenclature	Percent_ARV	Note
A	14304339	SENSOR UNIT,LASER DETECTING SET	24.95	- Careful physical control - Very reliable supplier - Frequent, small orders
	14427645	ENGINE,DIESEL	11.60	
	11516429	CONTROL DISPLAY UNIT	7.47	
	↓	↓ (total 12 parts)	↓	
B	10692638	RECEIVER-TRANSMITTER,RADIO	1.44	- Moderate control
	11954844	AMPLIFIER,RADIO FREQUENCY	1.37	
	11516431	TRAVERSE DRIVE	1.10	
	↓	↓ (total 30 parts)	↓	
C	219083069	STRUT ASSEMBLY,VEHICULAR SUSPENS	0.26	- Simple control rules - Larger, infrequent orders
	14582495	CABLE ASSEMBLY,POWER,ELECTRICAL,	0.25	
	11643377	CYLINDER ASSEMBLY,HYDRAULIC BRAK	0.25	
	↓	↓ (total 61 parts)	↓	

Table 6.2: ABC Analysis Table

In this case study, the first 12% of repairable parts in the list, class A, will account for approximately 75% of cumulative ARV. These items require careful physical

control and very reliable suppliers. The next, 30% of repairable parts, class B, will account for a further 20% of cumulative ARV, and the last 58% of repairable parts, class C, will account for a last 5% of cumulative ARV. These results are shown in the above table.

6.6 Data Mining Methods for the Classification of LAV-25 (E0947) SECREPS

With the statistical learning approaches, play as key roles in Data Mining, the input space can be divided into a collection of regions labeled according to the classification. From the current quadrant model analysis in USMC, the SECREPS for the LAV-25 can be classified into four classes, namely 'Routine', 'Bottleneck', 'Leveraged', and 'Critical'.

In the current quadrant model for the LAV-25 SECREPS, USMC use variable value and risk related information of the repairable parts to build two-by-two matrix.
With this information that can be obtained directly from their current practice, data mining approach can be considered as an effective alternative method for the classification of the SECREPS of the LAV in maintenance area. Following figure (6.4) shows the possible data mining approach for the classification of the LAV-25 SECREPS.

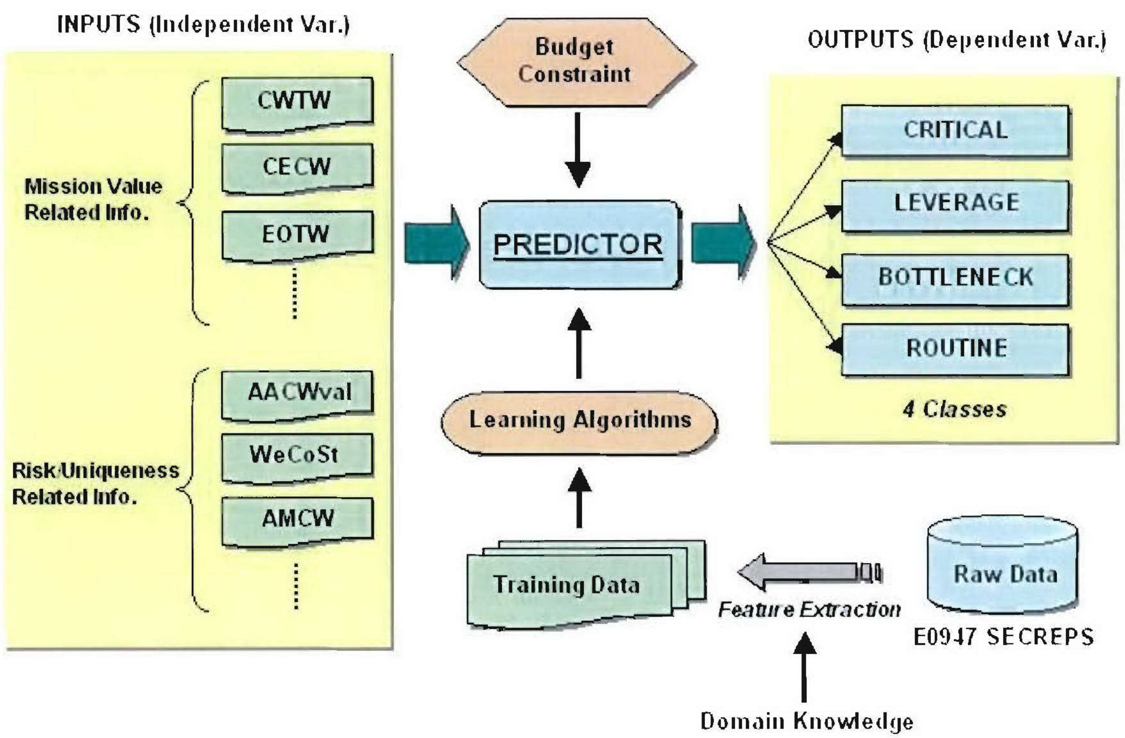

Figure 6.4: Data Mining Approach for the Classification of the LAV-25 SECREPS

7 Contemporary Research in Related Domains

The concept of autonomic logistics for maintenance envisions an information system that autonomously collects, processes and distributes the relevant data across the entities within the logistics chain. The condition based monitoring (CBM) [Appendix: 2 contain a list of websites which give detailed information on CBM, both from the commercial, DoD and Research views.] system on board the ground equipment can help accomplish the task of acquiring maintenance request data. This information has to be transferred to the nodes within the logistics chain and should consequently trigger the fulfillment processes. There is a need to develop a robust and standardized information flow that could render this possible. Moreover, processes enabling this have to be re-engineered to match the best practices prevailing within the maintenance industry today. This calls for re-engineering the existing logistics operations to fit the to be operational architecture.

The key focus of re-engineering the logistics chain is to improve its performance, flexibility, visibility and readiness. The logistics chain has to be systematically defined by specifying the different entities that make up the chain and their inter-relationships. Once this is accomplished, the performance of the logistics chain can be measured and evaluated using certain standard metrics. Matching the current performance of the logistics chain with the benchmarked expectations would enable us to control it by altering the relationships between the various entities within. Based on the above-mentioned information, the supply chain operations reference model (SCOR) was developed by the supply chain council. The SCOR model as the name suggests is a process reference model entailing the set of guidelines that help combine the elements of business process re-engineering, benchmarking and leading practices into a single framework. Under SCOR supply chain management is defined as these integrated processes - Plan, Source, Make, Deliver and Return – from the supplier's supplier to the customer's customer, all aligned with the company's operational strategy, material, work and information flows.

Though the SCOR model details the processes and metrics that can be adopted to define the logistics chain and evaluate its performance the following questions need to be answered before the SCOR project can be initiated to identify the processes involved and the corresponding information flows: Should the entire set of processes that enable supply and maintenance be viewed as a single chain? Do all the supply chain threads need to have an end-to-end visibility? The quadrant model is a logical and systematic approach that can be used to answer the above questions. The products and/or services moving through the logistics chain can be categorized into four quadrants and each quadrant will contain specific properties such as visibility, criticality of the product etc. This will help decide the scope of operational visibility required for each thread within the logistics chain and also to decide the priority that has to be used for the requests of a specific product family.

Analyzing the processes and identifying the information flows can facilitate identify the type of commercially available ERP systems. Though these systems can be out into place seamlessly integrating them into a single unified, enterprise application would prove critical to the successful implementation. Appendix: 10 presents a detailed review of the available literature on SCOR model as well as the considerations for enterprise application integration. The references used to generate the document are also provided within. It also looks into the emerging trends in enterprise integration that will push the performance levels of the system in the future.

8 Grounding the Study with an Exemplar

To ensure that the study does not only consist of abstractions and can be related to specifics it was decided to use a specific example. The choice of Light-Armored Vehicle (LAV) as a specific example was dictated by several considerations. First, it was indicated as the example to use in the task description. Second, the LAV is a family of vehicles that has been in operation for a number of years, is considered fairly successful and is undergoing a service life extension program (SLEP) making it an appropriate candidate for this project. Third, related projects for the LAV underway at Penn State ARL and at Rochester Institute of Technology have already undertaken the task of sensor integration for health monitoring of vehicles, which makes the LAV the appropriate platform for extending the work for the next step of prognostics and diagnostics for a family of vehicles.

Towards this end, one of the members of the team has made contact with Mr. Derald Schnepp at the Program Managers Office for the LAV at TACOM, Warren, MI. Following early discussions with Mr. Schnepp, we have received a description of current maintenance practices, as documented that is being studied by the research team. In addition to these, the team is awaiting scheduling of conference calls with Gunners at the PM office, who are primarily responsible for maintenance of the LAV. These early conversations will primarily focus on understanding the actual, as opposed to documented, maintenance practices used for the LAV. Finally, preliminary information about the work breakdown structure for the LAV has been obtained from Major Landry and the ARL at Penn State that is being studied by the research team.

9 Planned Work

Use Case Analysis

1. SECREPS Analysis/ Data mining
2. Sensor Processing Details
3. Functional Requirements of IDGE
4. Database Requirements
5. Shared Database Requirements/Elements
6. Diagnosis Methods
7. Prognosis Methods
8. Maintenance Practices and Systems
9. IT Infrastructure Requirements
10. ILC-IDGE-AL integrated framework – first cut architecture

10 Questionnaire

The below mentioned questions are related to the Quad Model SECREPS data:

1) What do the acronym stand for in each of the attributes?

2) What do they stand for?

3) Is there any mathematical formula behind them?

4) There are various sheets within one file; could you briefly explain what each stand for?

General Questions:

1) What type and details of information do Tactical, Operational and Strategic levels require?

2) What are the various types of Maintenance systems currently used?

3) What organizations/units of maintenance comprise within Depot, Intermediate and Organizational levels?

4) Brief description of BIT/BITE using an exemplar?

11 Appendices*

11.1 Appendix: 1 – OA, ILC, and GCSS-MC

11.2 Appendix: 1 – Enterprise Architecture

11.3 Appendix: 1 – Global Combat Service Support (GCSS-MC)

11.4 Appendix: 2 – URLs for Condition Based Maintenance

11.5 Appendix: 3 – Autonomic Logistics (AL) on Joint Strike Fighter (JSF)

11.6 Appendix: 4 – Sensor

11.7 Appendix: 5 – Condition Based Maintenance in Army

11.8 Appendix: 6 – Commercial Practices of Maintenance in Aviation

11.9 Appendix: 7 – Industrial Logistics Applications: Penske Case

11.10 Appendix: 8 – Maintenance and Automotive Telematics

11.11 Appendix: 9 – SCOR model and EAI system

* The Appendix is either a reproduction or summarization of the References mentioned within the Appendix.

11.1 Appendix: 1 – OA, ILC, and GCSS-MC

11.1.1 Operational Architecture

11.1.1 Operational Architecture (OA) Review
11.1.2 Summary on Integrated Logistics Capabilities (ILC)

11.1.2 Enterprise Architecture

11.2.1 Validation Series
11.2.2 Preliminary thoughts on Condition-Based Maintenance (CBM)

11.1.3 Global Combat Service Support – Marine Corps (GCSS-MC)

11.3.1 Summary on Global Combat Service Support (GCSS)
11.3.2 Summary on GCCS
11.3.3 Summary on GCSS-MC
11.3.4 Summary on GCSS-MC Strategy
11.3.5 GCSS – MC Process Summary
11.3.6 Summary on Autonomic Logistics

11.1.1 Operational Architecture

11.1.1.1 Operational Architecture (OA) Review

This section depicts the Operational Architecture for the "To-Be" Marine Corps logistics enterprise. The USMC Integrated Logistics Capability (ILC) team was tasked to develop a standard set of processes across the logistics enterprise, based on ILC concepts and commercial best practices. First ILC team developed the high-level OA that serves as the foundation for the follow-on efforts to develop the detailed OA for Global Combat Support System-Marine Corps (GCSS-MC). This section on Operational Architecture is organized to discuss the OA at a higher level of abstraction followed by a detailed description.

11.1.1.2 Scope and approach of OA

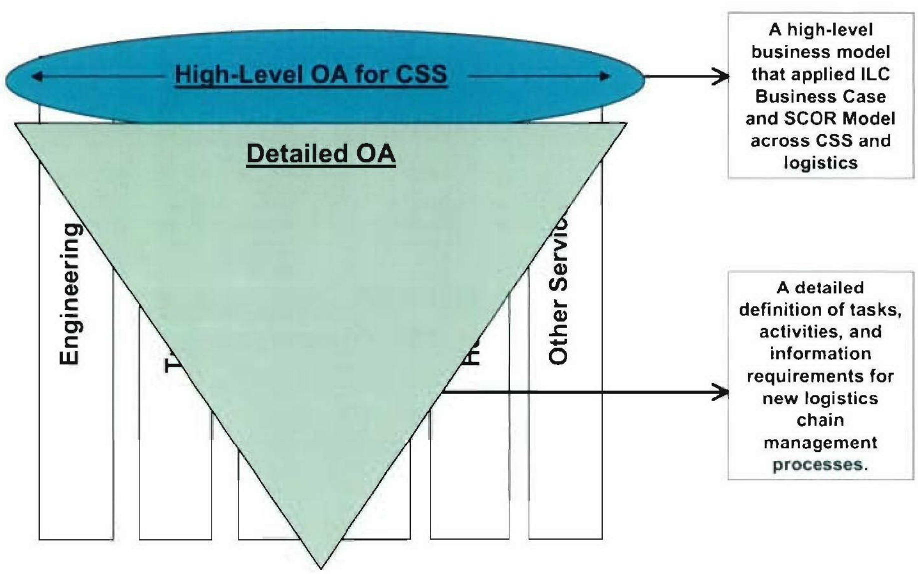

Figure 11.1: OA Scope and approach

The High-Level OA breaks down into the detailed OA where tasks, activities, and information requirements for new logistics chain management processes are defined.

The high level view of the Marine Corps' logistics chain reflects characteristics that are similar to the typical supply chain existing in commercial enterprises. For example, a typical commercial supply chain is comprised of two basic sets of activities –recognition of demand for products and services, and the fulfillment of

that demand. The Marine Corps' logistics chain can be described in these terms. The consumer creates demand for products or services, and a supplier fulfills that demand. Despite the similarities between the two, the Marine Corps' logistics chain differs from the commercial world. These differences are directly related to the organization, roles, and mission of the Marine Corps.

This fact brings up the necessity to build the context-specific detailed OA. The concepts in SCOR Model are used in describing the details of the OA. The SCOR Model breaks down business activities that are associated with satisfying consumer demand. The model outlines the steps of a logistics chain transaction, starting with the consumer inquiry through the paid invoice.

11.1.1.3 Review - High Level OA

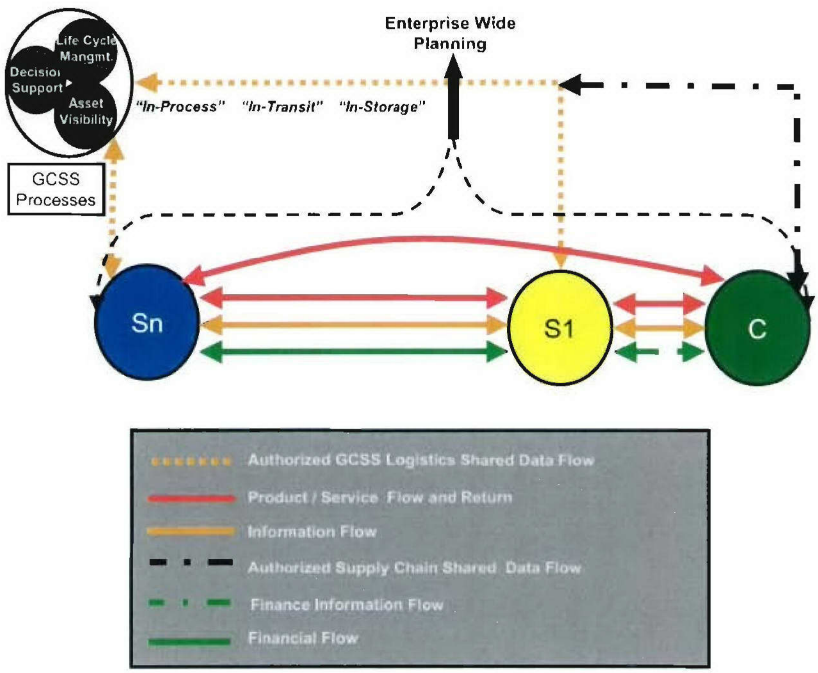

Figure 11.2: High-Level Operational Architecture

The Consumer in the "To-Be" logistics chain is defined as the ultimate consumer of products and/or services, such as a supported unit, and is depicted as "C" (Figure 11.2).

The consumer is responsible for generating demands, conducting operator level maintenance, and accounting for their resources. Demand may be reactive (e.g. unscheduled maintenance), or forecasted (e.g. scheduled re-supply), using manual (e.g. radio) and or automatic (e.g. autonomic) modes of communication. In the ILC architecture, consumer demands are passed to a single entity. This entity is depicted as Supplier 1, or the "S1" node (Figure 11.2). Supplier 1 is responsible for

all logistics chain processes including order management, sourcing and the delivery of products and services for the consumer. Its primary obligation is to fulfill the demand generated by the consumer, not necessarily to maintain a hierarchical relationship between itself and its supplier(s). It maintains inventory and asset visibility, has intermediate maintenance capabilities, and conducts financial management for the consumer.

Consumers communicate demand for products and/or services to Supplier 1 by any available means. The orange arrow in Figure 11.2 depicts the information flow. This link is the Consumer's interface with the logistics enterprise and includes other information such as order receipt, order status, and shipping information. Demand signals from the consumer lead ultimately to the flow of products and services up and down the supply chain.

Both product and service flows are depicted by the red arrow. Supplier 1 fulfills consumer demands from organic sources and is also responsible for managing financial resources for the consumer. Financial information (e.g., available funds, account reconciliation, etc.) is passed onto the consumer. This flow is depicted by the dashed green line, which is imbedded within the information flow (orange line).

Supplier 1 is responsible for communicating with all other suppliers, vendors and service providers (called Supplier(s) N, and depicted as "Sn"). Supplier(s) N replenishes demand generated from the Consumer at the request of Supplier 1. Within the Marine Corps, Supplier(s) N activities include (but are not limited to) wholesale supply, depot-level maintenance, and management of secondary repairables. In addition, Supplier(s) N's involvement with the logistics chain enterprise is based on its relationship to Supplier1. Examples of Supplier(s) N include the Defense Logistics Agency (DLA), clinical health care provided by the Navy, transportation services provided by TRANSCOM via GTN, commercial vendors, authorized civilian agencies, or even adjacent units.
The interaction between Supplier 1 and all other suppliers gives Supplier 1 the ability to pass a demand to the next node in the logistics chain (e.g., commercial vendor or DLA).

A critical element of the logistics chain is the availability of quality data across the enterprise. This demands, "sharing" of data and is enabled by a Shared Data Environment (SDE), which is used to facilitate the flow of data throughout the enterprise.

The SDE enables members of the logistics enterprise to maintain visibility of assets that are in transit, in storage and or in processing, and provides a means of accessing information by each node in the supply chain. The SDE, which is the cornerstone of GCSS-MC, provides data that is of uniform and consistent in structure. The SDE will also provide an easily accessible repository for common data necessary to provide rapid, flexible decision support, total asset visibility, an effective planning capability (across the enterprise), and an enhanced ability to execute lifecycle management.

11.1.1.4 Review - Detailed OA

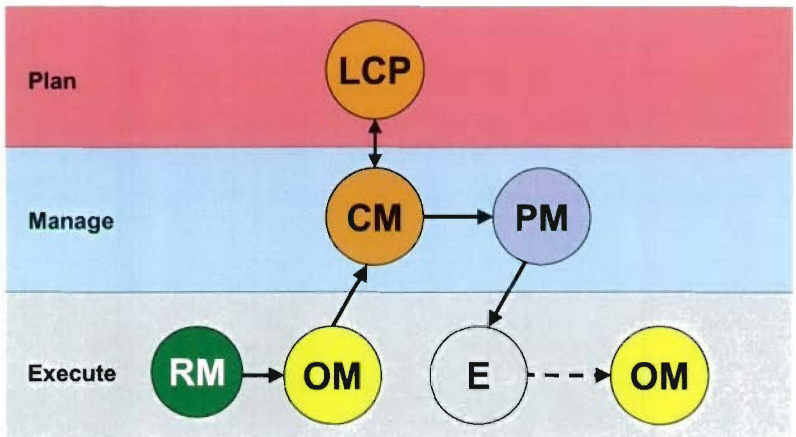

Figure 11.3: High-Level Functional Context Diagram

We will briefly explain the processes in this section. In section 11.1.1.4, we undertake a detailed explanation. Readers familiar with the OA processes can skip section 11.1.1.5.

Logistic Chain Planning (LCP) is located in the enterprise level. The duty of LCP is planning and designing logistic chain to fulfill customer's demands.

Request Management (RM) is the function for generating and approving customer demands. Basically, it works by validating customer requirements and generating requests for logistics support (fulfillment of products and services) if required. RM receives requirements from within the customer / supported unit; prioritizes requirements, sources the demand internally or processes the requirement into a request and submits the request to be created into an order.

Order Management (OM) is the function for routing, coordinating, tasking, and tracking customer orders through fulfillment. This function works by receiving requests from customers, generating customer orders (based on requests) and initiating the fulfillment of products and services. In addition, OM processes communicate order status to the customer.

Capacity Management (xCM) is the function that involves managing, optimizing, prioritizing, and planning resources and capacity to fulfill customer demands. It can

be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can again be divided into other sub-categories.

Production Management (xPM) is the function for coordinating, planning, tasking and controlling how customer demands are fulfilled. It can be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can then be divided into other sub-categories.

Execution (xE) is the function for executing CSS tasks to fulfill customer demands. It can be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can be divided into other sub-categories.

11.1.1.5 Operational Architecture Review: Functional Process Flows and Operational Elements

Request Management (RM) is the function of generating and approving customer demands. Basically, it works by validating customer requirements (at an individual and aggregate level) and generating requests for logistics support (fulfillment for products and services) if required. Request Management is the customer's process of approving and generating its demands for logistics support. RM receives requirements from within the customer / supported unit; prioritizes requirements, sources the demand internally or processes the requirement into a request and submits the request to be created into an order.

The purpose of Request Management is to gather requirements at an individual or aggregate level, validate and understand the nature of the customer's requirement and to ensure that requests for products and services can be supported through capabilities in the logistics enterprise. This process also provides a means to validate requirements at the aggregate level to achieve potential economies of scale in fulfilling customer requests.
It can be divided into 4 functional flows:

- Request Management Product (RMP)
- Request Management Return (RMRL)
- Request Management Service (RMP (D))
- Request Management Service (RMP(M))

Order Management (OM) is the function of routing, coordinating, tasking, and tracking customer orders through to fulfillment. This function works by receiving requests from customers, generating customer orders (based on requests) and initiating the fulfillment of products and services. The activities in the OM process enable the Order Management function to manage customer orders from start to completion by coordinating and decomposing requirements with and among enterprise capacities and capabilities to facilitate fulfillment of the order and to communicate order status to the customer.

The purpose of the Order Management process flow is to generate customer orders, initiate the process of product and service fulfillment, and coordinate and/or decompose all related logistics activities among the various Capacity Management activities. The Order Management process binds all related child orders to the primary order generated through the Order Management process. From the customer's perspective, the Order Management process centralizes the fulfillment process at one point within the logistics chain enterprise allowing for more efficiencies and coordinated efforts in the fulfillment process.

It can be divided into 5 functional flows:

- Order management Product (Pre & Post) (OMP)
- Order management Return (Pre and Post)(OMRL)
- Order management Service (Distribution) (Pre and Post) (OMS(D))
- Order management Service (Maintenance) (Pre and Post)(OMS(M)), and Customer Service Management (CUSTSRV-MGT)

The last one, Customer Service Management (CUSTSRV-MGT) is the process of receiving, validating, identifying, analyzing and managing the resolution of customer issues or inquiries.

Logistic Chain Planning (LCP) is located in the enterprise level. The duty of LCP is planning and designing logistic chain to fulfill customer's demands. LCP can divided into 11 subcategories as shown below

1. Logistic Chain planning - Back End (Provider Facing, LCPLAN-PRO): This flow focuses on segmenting providers into various categories and developing appropriate provider relationships with the goal of reducing the total cost of procurement and increasing collaboration. Purpose: to establish stronger relationships with providers. These strengthened relationships will lead to improvements in cycle time and elimination of waste that will result in increased effectiveness of the USMC logistics enterprise. This process also provides a common standard for comparing performance of various providers and will enable the USMC to rank and evaluate providers.

2. Logistic Chain planning - Front End (Customer Facing, LCPLAN-CUST) LCPLAN-CUST is the process of establishing customer support agreements, based on customer needs and mission priorities, to support the customer in achieving their objectives. It helps to refine the review process developed to understand customer support requirements and to provide a communication channel for customer feedback.
   Purpose: to create customer support agreements that will be used to define the level of support provided to help customers meet their objectives. The process also is used to refine the customer support review process used to communicate with customers and share requirements both from a customer and a support capabilities perspective.

3. Network Design Planning (NETDES)
   NETDES is the planning process by which the enterprise plans and manages the location, capacity and capabilities of its logistics infrastructure. The logistics network is the physical channel by which products and services are provided to the supported unit. Planning is done to configure and reconfigure the nodes and resources employed in the logistics chain network to optimize its efficiency.
   Purpose: to identify additional network capabilities required to support logistics chain goals and objectives. The logistics network must effectively meet the needs of the supported unit. Effectively managing the flow of product and services through the logistics network is critical to responding to the customer's requirements. Network design planning facilitates a cost-effective and responsive logistics network to support the customer.

4. Customer Service Planning (CUSTSVRPLAN)
   CUSTSVRPLAN is the process of capturing and analyzing data and developing a plan to identify preventative / pre-emptive measures to reduce or eliminate anticipated service failures and/or customer issues at the enterprise level.
   Purpose: to identify service remedy plans that can be used to resolve customer issues (through the customer service management process) and to recommend changes to logistics chain processes to eliminate or reduce anticipated service failures.

5. Life Cycle Management (LCM)
   Life Cycle Management emphasizes decision processes that influence system cost and usefulness efficiencies. The primary objective of life cycle management is to deliver quality systems when promised and within cost estimates using an identifiable, measurable, and repeatable process.

6. Maintenance Planning (MNTPLAN)
   MNTPLAN is the process of determining the maintenance requirements for all assets that need maintenance in an enterprise. The outcome of the Maintenance Planning process is to conduct preventative maintenance so that corrective maintenance is minimized. This approach will ensure the highest equipment availability possible throughout the equipment's life cycle.
   Propose: to plan for maintenance proactively so that all the maintenance requirements over the long term (12 to 18 months) are gathered and assessed against the available resources at the enterprise level.

7. Maintenance Allocation Planning (MNTALC)
   MNTALC is the process of allocating maintenance resources to maintenance requirements for all assets that need maintenance in an enterprise over a regular time period. Yet, it allocates a gross requirement to resources.
   Purpose: to provide an estimate of all the anticipated maintenance requirements so that appropriate stakeholders can plan the use of their assets. This plan will give stakeholders (i.e. operators of the assets) an

idea about when their assets are going into the maintenance cycle. This also allows the stakeholders to plan their resources accordingly.

8. Procurement Planning (PROCPLAN)
Procurement planning is the process of developing a strategy to replace a capability with a commercial or DoD entity, increase capacity, or provide a sourcing strategy to meet enterprise goals.
Purpose: to produce a Procurement Plan that contains the activities required to modify the capacity of the provider and buying network to meet expected logistics chain requirements. These activities include qualification of new providers, identification of new ways to purchase, adjustment of provider contracts/agreements, identification of new products and services, etc.

9. Inventory Planning (IMPLAN)
IMPLAN is the process of planning what inventory (by item / item category) is required, how much should be held, where it should be held (location) and when it should be reordered to support current and future demands at the enterprise level.
Purpose: to meet anticipated demand and to determine the business rules and control parameters (e.g. order frequency, stock level thresholds, service levels, physical properties, etc.) required to effectively manage an enterprise's inventory. Ultimately, this process will help ensure that inventory is managed (i.e. positioned, monitored, replenished and controlled) according to established logistics chain objectives (i.e. balancing effectiveness/efficiencies), changing customer needs, and unexpected variances in the demand/supply environment.

10. Demand Planning (DEMPLAN)
DEMPLAN is the process of collecting, segmenting and analyzing data related to historical planned and unplanned product and service consumption, as well as known anticipated consumption (e.g. operations and exercises) at the enterprise level.
Purpose: to produce a demand forecast that anticipates future consumption. This forecast is based on the synthesis of customer and other segmentation criteria and enterprise constraints (budgetary, regulatory etc.); ultimately resulting in a forecast that anticipates and fulfills the demands of the customer.

11. Return Planning (RETPLAN)
RETPLAN is the process of collecting, segmenting and analyzing data related to historical planned and unplanned product and service returns, as well as known anticipated returns at the enterprise level.
Purpose: of the process is to produce a return forecast that anticipates future returns based on customer and other segmentation criteria. After applying constraints (budgetary, regulatory etc.) a forecast that meets the satisfaction of the customer can be used in the inventory planning and service capacity planning processes to drive requirements.

Capacity Management (xCM) is the function that involves managing, optimizing, prioritizing, and planning resources and capacity to fulfill customer demands. It can be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can be divided into other sub-categories that will be described below.

Distribution Capacity Management (DCM) is the function that involves managing and planning the distribution strategy which can be divided into 10 functional flows as list below.

1. Transportation Planning: Facility Location Capacity Planning (TRNS-FAC-LOC)
   TRNS-LOC is the process of determining the location and capacity of facilities within the distribution network. This process is primarily driven by distribution requirements identified in other planning processes. The strategy that guides this process is defined in the Network Design Plan. Purpose: to plan for the necessary facility infrastructure to satisfy projected distribution requirements within a particular geographic area. In this process, existing infrastructure is examined and capabilities are compared against requirements to identify excesses or deficiencies.

2. Transportation Planning: Transportation Capacity Planning (TRNS-CAP)
   TRNS-CAP is the process of determining required capacities of the links between nodes within the distribution network. These decisions are driven by distribution requirements and logistics strategies. Links can be modified, added, or removed to satisfy required capacities. Purpose: of this process is to provide a way of examining existing link infrastructure and comparing it against forecasted distribution requirements to identify future needs. Link capacities can be modified to enhance the flexibility of the distribution network, to plan for contingencies with alternative options, and to respond to changes in demand.

3. Transportation Planning: Facility Resource Planning (TRNS-FAC-RES)
   TRNS-FAC-RES determines the resource requirements for facilities that are necessary to meet distribution service demands. This process takes into account various factors such as throughput requirements, available resource options, and the available facility budget to arrive at the optimal resource plan. Purpose: to plan the resources required to realize the planned capacity. Resources are required at each facility to fulfill distribution services associated with the facility operating attributes. These resources can include personnel, service equipment, financial budgets, and other resources. The quantity of required resources at a facility is dependent on the distribution volumes, desired throughput and facility operating attributes.

4. Transportation Planning: Mode Planning (TRNS-MODE)
   TRNS-MODE determines the primary and alternate modes of transportation used between origin / destination pairs, series, or corridors in the distribution network based on forecasted demand for distribution services.

Purpose: to develop a rough cut plan of which modes are most appropriate to carry shipments between particular locations within the transportation network. This plan is used to guide selection of compatible routes, transportation resources, and configuration of the transportation fleet.

5. Transportation Planning: Route Configuration Planning (TRNS-ROU-CFG)
TRNS-ROU-CFG determines the primary routes between Origin / Destination pairs or a series of locations that can best satisfy link capacity requirements identified in Transportation Capacity Planning. This determination is based on various factors such as required distribution volumes, the range of products and services to be transported, and route characteristics such as available time windows and vehicle compatibility.
Propose: to satisfy the Transportation Capacity Planning with actual routes. A route can be a series of roads, airways, sea-lanes, or any other type of path between locations. It is necessary to identify multiple routes for each transportation link, so that alternative options are available to handle changes in volume or other contingencies.

6. Transportation Planning: Fleet Configuration Planning (FLEET-MGMT)
FLEET-MGMT determines the mix of transportation assets that best satisfies the distribution requirements, with consideration to the other aspects of distribution planning. This process also determines the pool points within the logistics network where the transportation fleet should be based to provide the highest level of service.
Propose: to generate the optimal fleet mix (air, ground, etc.) to satisfy service requirements. The fleet configuration decision balances requirements and the desired service levels against cost. This process studies what is achievable, and how to achieve these goals.

7. Transportation Planning: Transportation Allocation Planning (TRNS-OP)
TRNS-OP is the process of allocating forecasted distribution volumes to selected routings for all distribution services over a period of time. While distribution volumes are forecasted across transportation links, there may be multiple routes that traverse each link. The distribution capacity for each link is allocated to individual routings in this planning process.
Purpose: to refine the Transportation Capacity Plan, using the Route Configuration Plan and the Mode Optimization Plan, to determine how much capacity is required along each route.

8. Transportation Planning (Delivery Planning): Mode Optimization Planning (FLEET-MODE)
FLEET-MODE determines the optimal and alternate modes for deliveries between origin / destination pairs, series, or corridors in the distribution network based on distribution scenarios.
Purpose: to optimize the mix of the modes that are most appropriate to carry shipments between particular locations within the transportation network, after the fleet mix has already been determined.

9. Distribution Capacity Planning (DSTCAP)
   DSTCAP determines the required capacity within the area of operations to meet current and forecasted demand. Decisions regarding the location of capacity and the control parameters, such as throughput, link and mode capacity, and service levels that are used to manage capacity, are also resolved in this plan.
   Purpose: to plan for distribution capacity proactively and manage separate categories of capacity so that appropriate business rules are applied and a distribution capacity plan can be generated.

10. Distribution Capacity / Operations Management (DSTCAPOPS)
   DCTCAPOPS is the process of scheduling and reserving capabilities and capacity to support fulfillment requirements for distribution services. These requirements can be generated by actual customer demand, or additional demand driven by fulfillment of other services. This process also performs the management of capacity utilization to meet established performance goals and satisfy changing requirements.
   Purpose: to make decisions, (e.g., reservation of distribution capacity to a customer order, relocation of required resources), to ensure that the necessary capacity is available to meet demand. This process also serves to coordinate with other logistics capacity management functions to ensure that requirements are understood.

<u>Inventory Capacity Management (ICM)</u> can be divided into 2 subcategories as described below

1. Inventory Capacity / Operations Management (INVCAPOPS)
   INVCAPOPS is the process of scheduling and reserving capabilities and capacity to support overall fulfillment requirements for product demand. These requirements can be generated by actual customer demand, additional demand driven by fulfillment of other services, or replenishment requirements. This process also performs the management of capacity utilization to meet established performance goals and satisfy changing requirements.
   <u>Purpose:</u> to make decisions (e.g., reservation of inventory capacity to a particular customer order, relocation or rescheduling of required resources) to ensure that the necessary capacity is available to meet demand. This process also serves to coordinate with other logistics capacity management functions to ensure that requirements are understood and that the fulfillment of product needs to customers can be coordinated, measured, evaluated and managed to meet expectations.

2. Inventory Control / Demand-Supply Management (DEMSUP)
   DEMSUP is the process of analyzing and correcting variances in demand and supply due to imbalances between actual and planned consumption, and managing the adjustment of resources (inventories and/or capacities) required to correct the imbalance.
   <u>Purpose:</u> to account for inaccuracies in forecasted demand and inventory

and capacity planning, which result in adjustments to inventory and / or resources required for actual consumption to be satisfied.

Maintenance Capacity Management (MCM) can be divided into 2 subcategories as described below

1. Maintenance Capacity Planning (MNTCAP)
   MNTCAP is the process of deciding what capacity (by type / category) is required and how much capacity is needed to support current and future demands. Decisions regarding location of capacity and the type of control parameters, such as order frequency, lead-times, service levels, etc., are determined in this plan.
   Purpose: to plan for maintenance capacity proactively. Additionally, this plan enables the enterprise to manage separate categories of capacity so appropriate business rules can be applied and a Maintenance Capacity Plan can be generated.

2. Maintenance Capacity / Operations Management (MNTCAPOPS)
   MNTCAPOPS is the process of scheduling and reserving capabilities and capacity to support overall fulfillment requirements for maintenance services.
   Purpose: of this process is to make decisions (e.g., reservation of maintenance capacity to a particular customer order, relocation or rescheduling of required resources) to ensure that the necessary capacity is available to meet demand.

Procurement Capacity Management (PCM) can be divided into 1 subcategory as described below

1. Procurement Capacity / Operations Management (PROCAPOPS)
   PROCAPOPS is the process of scheduling and reserving capabilities and capacity to support overall sourcing requirements. These requirements can be generated by actual customer demand, additional demand driven by fulfillment of other products and services, or replenishment requirements.
   Purpose: to make decisions to ensure that the necessary procurement capacity is available to meet demand. This process also serves to coordinate with other logistics capacity management functions to ensure that requirements are understood and that the fulfillment of product needs to customers can be coordinated, measured, evaluated and managed to meet expectations.

Production Management (xPM) is the function of coordinating, planning, tasking and controlling how customer demands are fulfilled. It can be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can be divided into other sub-categories that will be described below.

Distribution Production Management (DPM) is the ability to manage the distribution strategies after planning processes are determined. It can be divided into 2 subcategories of functional flows as described below.

1. Distribution Production / Operations management (DSTOPS)
   DSTOPS is the process of scheduling and reserving specific resources to support overall fulfillment requirements for distribution services. In addition, the Distribution Operations Management function will also adjust schedules and or resources according to feedback from the execution function.
   Purpose of this process is to make decisions, (e.g., reservation of specific distribution resources to a particular customer order, relocation or rescheduling of required resources), to ensure that the necessary resources are available to meet demand.

2. Transportation Planning (Delivery Planning) – Route and Schedule Planning (TRNS-ROU-SCH)
   TRNS-ROU-SCH determines the primary routes and schedules for the delivery of products and services. Running various scenario driven models and selecting the best solution determines the planned routes and schedules.
   Propose: to establish a schedule for the execution of distribution tasks or deliveries. This process covers scheduling and routing of deliveries for the logistics enterprise to meet distribution requirements generated by Inventory Planning, Maintenance Planning, and other planning processes. The schedule solution should be designed in accordance with vehicle maintenance requirements, mode capabilities, and operator limitations such as the maximum number of driving hours/day.

Inventory Production Management (IPM) is the ability to manage the inventory strategies after planning processes are determined. It can be divided into 1 subcategory of functional flows as described below.

1. Inventory Production / Operations Management (INVOPS)
   INVOPS is the process of scheduling and reserving specific resources to support overall fulfillment requirements for product demands. In addition, the Inventory Operations Management function will also adjust schedules and / or resources according to feedback from the execution function.
   Purpose: to make the management decisions, around inventory execution, required to ensure the necessary resources are available to meet demand for product fulfillment.

Maintenance Production Management (MPM) is the ability to manage the maintenance strategies after planning processes are determined. It can be divided into 2 subcategories of functional flows as described below.

1. Maintenance Production / Operations Scheduling (MNTSCH)
   MNTSCH is the process of scheduling maintenance resources against specific assets that need maintenance. The Maintenance Allocation Plan drives the scheduling process. The Maintenance Scheduling process commits resources to specific tasks with specific time associated with each item so that maintenance is performed at a scheduled time
   Purpose: to schedule equipment for maintenance at specific dates and

times. This process bridges the gap between the Maintenance Allocation and the Maintenance Operations processes and can be viewed as a further decomposition of the "Schedule and Reserve Specific Resources" activity in the Maintenance Operations Management process flow.

2. Maintenance Production / Operations Management (MNTOPS)
   MNTOPS is the process of scheduling and reserving specific resources to support overall fulfillment requirements for maintenance services. In addition, the Maintenance Operations Management function will also adjust schedules and or resources according to feedback from the execution function.
   Purpose: to make decisions (e.g., reservation of specific maintenance resources to a particular customer order) to ensure that the necessary resources are available to meet demand. This process coordinates with the Maintenance Capacity Management function to ensure that requirements are understood and that the fulfillment of maintenance services to customers can be measured evaluated and managed to meet customer expectations (quality order concept).

Procurement Production Management (PPM) is the ability to manage the maintenance strategies after planning processes are determined. It can be divided into 1 subcategory of functional flows as described below.

1. Procurement Production / Operations Management (PROCOPS)
   PROCOPS is the process of training and applying sufficient resources to execute procurement actions based on the anticipated volume and complexity of the requirements. In addition, the Procurement Operations Management function will also adjust schedules and or resources according to feedback from the execution function.
   Purpose: to manage the execution of procurement actions based off the procurement plan to ensure that the necessary resources are available to fulfill product and service demands. This process coordinates with the procurement capacity management function to ensure that requirements are understood.

Execution (xE) is the function of executing CSS tasks to fulfill customer demands. It can be divided into 4 categories (Distribution, Inventory, Maintenance and Procurement) each category can be divided into other sub-categories that will be described below.
Distribution Execution (DE) is the execution of distribution strategy to fulfill the customer demands which can be divided into 1 subcategory as described below.

1. Distribution Fulfillment (OFS(D))
   OFS(D) is the process of executing distribution as part of a customer order for products and services. Distribution fulfillment may entail delivering a product to a customer or include transportation of equipment. Distribution fulfillment is also the process used to move the customer and/or equipment

to another location.
Purpose: to execute distribution of product and resources to meet customer requirements for product and service fulfillment.
It also related to a customer requirement for product or services, begins with a service order linked to a customer order. The service order may have been initiated due to a product or returns order, due to a maintenance service order, or due to some other customer need requiring distribution services. The service order may also be a request for transportation services not related to product or services fulfillment, (i.e. movement of personnel, equipment or a stand alone transportation order).

Inventory Execution (IE) is the execution of inventory strategy e.g. packing, picking items to fulfill the customer demands which can be divided into 2 subcategories as described below.

1. Warehouse Management Outbound (WMO)
   WMO is the process of picking, packing and shipping items for fulfillment of customer orders or replenishment of inventories at other locations.
   Purpose: to execute the outflow of items from a location for fulfillment of existing and anticipated product orders either initiated through a product or service order.

2. Warehouse Management Inbound (WMI)
   Inbound Warehouse Management is the process of receiving items from providers (internal and external), verifying and recording assets received, recording and reporting discrepancies and storing the items for the fulfillment of anticipated customer orders. The process includes cross-docking operations for the fulfillment of existing customer orders.
   Purpose: to execute the inflow of items from internal and external providers and to ensure that the items are appropriately stored for fulfillment of existing and anticipated customer orders initiated through a product or service order.

Maintenance Execution (ME)

1. Maintenance Fulfillment (OFS(M))
   OFS(M) is the execution of inventory strategy e.g. packing, picking items to fulfill the customer demands which can be divided into 2 subcategories as described below.
   Purpose: to identify the activities necessary to fulfill any maintenance demand that has been initiated through the logistics chain enterprise. The activities identified in the flow represent the execution component of the maintenance process.

Procurement Execution (PE)

1. Procurement Execution Fulfillment (PROCFUL)
   PROCFUL is the process of fulfilling sourcing requirements for products and services that originate either through order fulfillment or through inventory replenishment.
   Purpose: to fulfill sourcing requests, using the most appropriate providers and options and leveraging existing / new options and capacities. This process also tracks the progress of a sourcing request(s) through to satisfaction of the sourcing requirement.

11.1.2 Summary on Integrated Logistics Capabilities (ILC)

The Integrated Logistics Capabilities (ILC) effort began in 1998 as a unique collection of military, industry and academic organizations collaborating to develop a future vision of Marine Corps logistics processes. In this effort, a transformation strategy based on best practices in industry is implemented to provide the framework for the execution of agile, effective logistics support to the Marine Air-Ground Task Force. Since one of the fundamental advantages that the Marine Corps maintains over other service components is the ability to provide self-sufficient, expeditionary logistics support, the era of Marines satisfying complex logistics problems with mass (people, supplies, and equipment) has passed. Transformation to meet the challenges of tomorrow is a fundamental objective for the ILC.

ILC is a key concept for US Marine Corps to revolutionize its logistics supply chain during this era of information technology. The philosophy behind ILC is to enable the maintenance of a Shared Data Environment (SDE) and further enterprise-wide planning based on real time and accurate information, so that the holistic metrics of a global supply chain can be optimized. Until now, the ILC team in US Marine Corps has developed Enterprise Architecture, especially high-level operational architecture, and some validation series.

11.2 Appendix: 1- Enterprise Architecture

Architecture can be described with the combination of three major views: operational, systems, and technical views. The Marine Corps integrated logistics system is not an exception. The operational architecture view is a description of the tasks and activities, operation elements, and information flows required to accomplish or support a military operation. The system architecture view is a description, including graphics, of systems and interconnections providing for, or supporting, warfighting functions. The technical architecture view is the minimal set of rules governing the arrangement, interaction, and interdependence of system parts or elements, whose purpose is to ensure that a conformant system satisfies a specified set of requirements. In a word, the operational view identfies warfighter relationships and information needs; the systems view relates capabilities and characteristics to operational requirements; the technical view prescribes standards and conventions. The development of ILC provides the ontology for different views with graphical and text primitives. Currently, the development of the operational view, i.e. ILC high-level OA, has been completed due to the completion

of the operational architecture. However, the development of the systems and technical views are left for the future work.

The ILC high-level OA integrates current CSS/logistics functions with common, high-level management processes based upon a universal supply-chain model. The "To-Be" ILC high-level OA provides an enterprise wide, integrated view of logistics focused on fulfillment of the demands for products and services generated by the warfighter. The approach used for developing ILC high-level OA adopts the Supply Chain Operational Reference (SCOR) model. Rather than concentrate on the vertical or functional "stove pipes" of the current logistics enterprise, the OA team employed a horizontal or process-oriented view across all of Marine Corps logistics.

The high-level operational concept description is summarized in the following. The Consumer is defined as the ultimate consumer of products and/or services, and is depicted as "C". Its main responsibilities include demand generation, operator level maintenance, and accountability. Consumer demands are passed to a single entity. This entity is depicted as Supplier 1, or the "S1" node. Supplier 1's responsibilities include demand fulfillment, all CSS functions, intermediate level maintenance and financial management. The flows between a "C" node and a "S1" node can be product and/or service, information (including financial information) flows.

Supplier 1 is responsible for communications with all other suppliers, vendors and service providers, which are called Supplier(s) N, depicted as "Sn". Supplier(s) N's responsibilities include demand fulfillment, SECREP (Secondary Repairable) Management and depot level maintenance. The flows between a "S1" node and a "Sn" node can be product/service, information and financial flows. In some cases, there may a direct product/service flow between a "Sn" and "C" nodes, although the "S1" node has to be informed.

From the above description, the ILC high-level OA requires the flow of data throughout the enterprise. It is enabled by a Shared Data Environment (SDE). The SDE consists of four layers, which are infrastructure layer, data layer, system layer and part of the business layer, from the bottom to the top. The representatives in the infrastructure layer are computer system and network devices. In the data layer, database and flat file systems store all the necessary data and information. In the system layer, application servers and database management systems provides the tools for the extraction and query of information. In the business layer, business rules are defined as the bridge between the system layer and the presentation layer, which defines enterprise portal. The SDE is depicted in Figure 11.4.

The SDE enables real time supply chain planning based on current and accurate information. To facilitate the planning process, data from the execution activities can be fed back, via the SDE, to the planning elements throughout the supply chain. This creates a continuous, cyclical flow of information between plan and execution activities.

In summary, the high-level operational concept graphic depicts a logistics enterprise that is optimized for a deployed environment, provides a clear customer focus enabled by standard processes, well-defined activities and integrated information technology in an SDE.

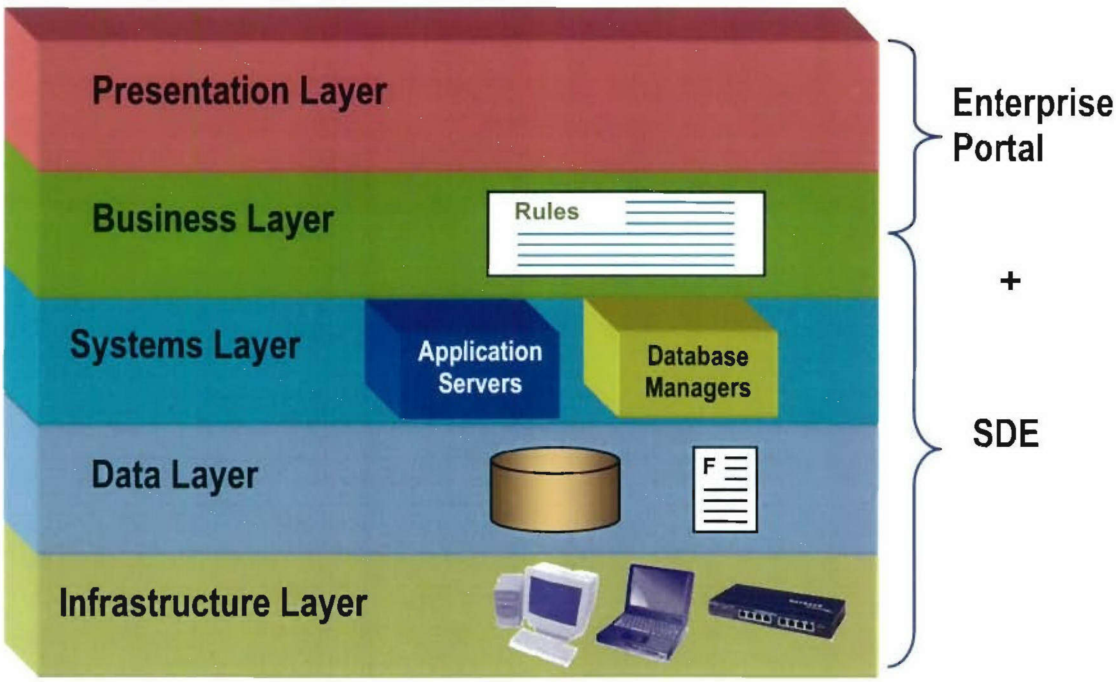

Figure 11.4: Architecture of SDE

11.2.1 Validation series

The Validation Series is a phased implementation of process improvements and Information Technology through a series of real world requirements validation initiatives within the Operating Forces. The Validation series is an iterative process, a continuous implementation and refinement of efforts designed to demonstrate the vision of enhanced and more responsive logistical support to the MAGTF. Key metrics, developed in conjunction with the OA, will allow the Marine Corps to measure the benefits and, if necessary, make course corrections to logistics processes, as required. In the following, key metrics and three analysis assessments by Navy are summarized.

Currently, the Marine Corps uses numerous metrics to measure everything from how many miles material has been transported (Ton Miles); to the number of orders that are filled from inventory on hand. To evaluate the ILC concept, they defined six categories of metrics: reliability, responsiveness, flexibility, readiness, assets and expense.

Reliability is measured by Quality Order Fulfillment. Responsiveness is measured by Total Logistics chain Cycle Time. Logistics chain flexibility is prescribed by the capacity available to handle sudden demand surges. Operational Availability metric has been selected as the Readiness attribute's tier-one metric. Assets are measured by Asset Utilization. The proposed expense metric is Total Logistics chain Expense.

Navy produced three assessment reports, which are summarized in the following. Their analysis shows that ILC enables great improvement on their logistics supply chain.

In the interim assessment, they report the following results:

- Improved supply response time
- Improved overall repair cycle time
- Delta TAMCN (Table of Allowance Material Control Number) readiness rebounding
- Indications that maintenance quality may improve in future through improved training of maintenance personnel
- However, customer satisfaction with logistics support has declined

In the first-year assessment, the following results are observed:

- Improved supply response time
- Improved overall repair cycle time
- No significant changes in readiness
- Indications that maintenance quality may improve in future through improved training of maintenance personnel
- Customer satisfaction with logistics support has declined, though there are recent signs of improvement

In the mid-term assessment, the following results are obtained:

- Materiel readiness rates: Readiness rates stayed fairly constant for all except Delta TAMCNs.
- Repair cycle time: median RCT tends to be a slight decrease and 95th percentile shows a dramatic drop (from 214 to 134 days).
- Number of repair tasks: the number of repair tasks per personnel has been dramatically increased (234%).
- Supply response time: The median supply response time has decreased. It is observed that a drastic reduction in the variability of supply response time during the last few months as compared to the baseline period.
- Time allocation (maintenance): no apparent improvement
- Training quality for maintenance personnel: more Marines are working on duties within their MOS (Military Occupational Specialties) than before. In addition, in many cases, confidence in performing ITSs (Individual Training Standards) within individual MOSs has increased.
- Time allocation (supply): the total amount of time spent by supply personnel on supply activities remains between 45 percent and 55 percent of their time at work. However, the amount of time spent on warehouse activities

increased substantially, compared to the baseline, while the amount of time spent on property control decreased.

- 'Quality': The percentage of respondents rating overall quality of maintenance support either poor or fair rose to 46%, compared to 22% in the baseline. At the same time, the percentage rating overall support either good or excellent dropped to 16% from 46%.

11.2.2 Preliminary thoughts on Condition-Based Maintenance (CBM)

In the development of condition-based maintenance system, ILC concept, especially its SDE and enterprise-wide planning, can be very useful. The SDE will enable the sensor and diagnostics information to be effectively stored and accessed. The key point of SDE is to provide the decision makers transparent visibility. The enterprise-wide planning system is a real time scheduling system, which bring intelligence to the supply chain. Hopefully, high-performance anytime algorithms that have the ability to keep the virtual plans can be developed to make full use of the real time and accurate information. The detailed ideas will be presented in the future.

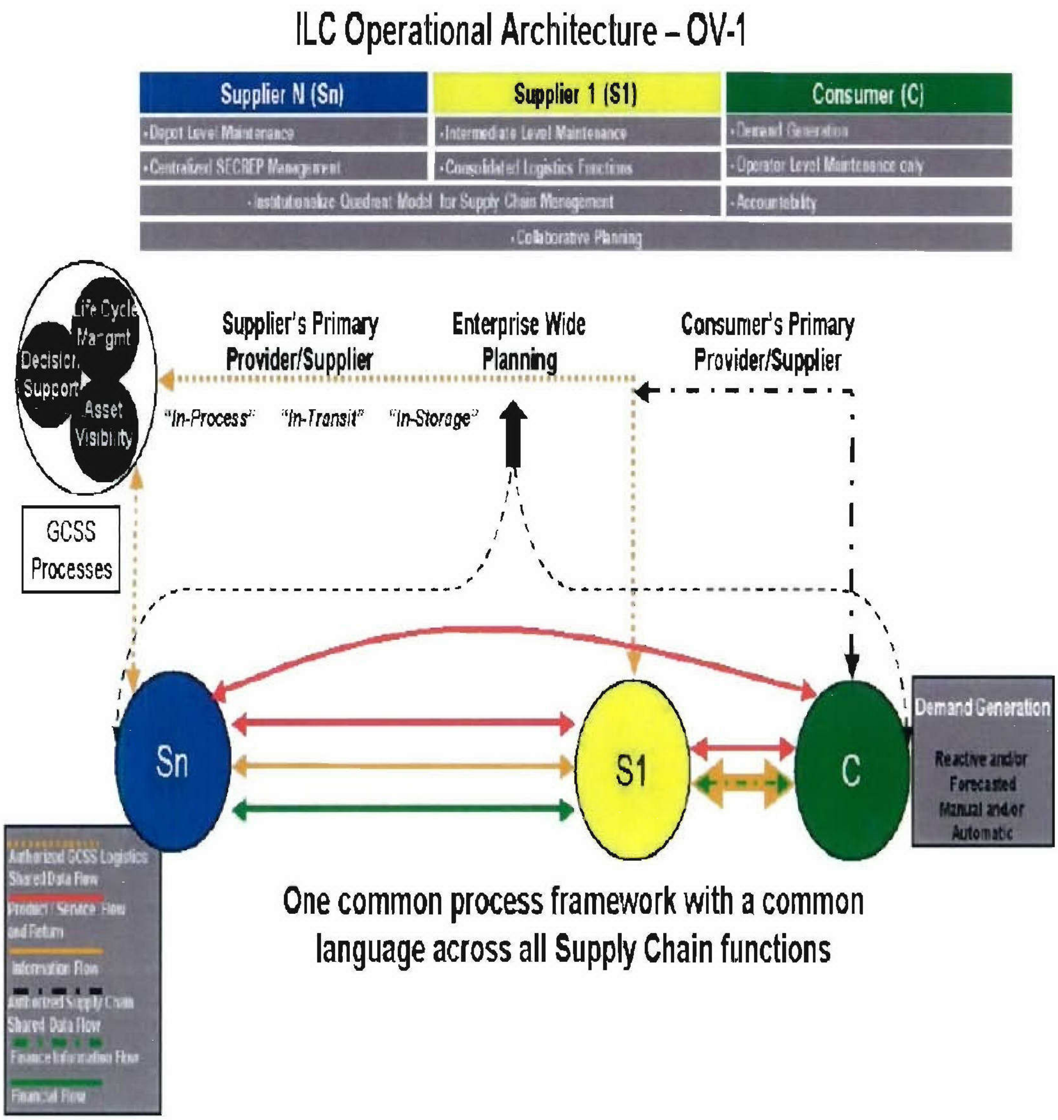

Figure 11.5: ILC high-level OA

11.3 Appendix: 1- Global Combat Service Support – Marine Corps (GCSS-MC)

11.3.1 Summary on Global Combat Service Support (GCSS)

The Global Combat Support System (GCSS) is a Family of Systems that provides information interoperability across combat support functions and between combat support and command and control functions in support of the Joint War Fighter. GCSS is the war fighter's tool to capture essential data, transform it into usable information, and gain information superiority to the success of maintaining force readiness and winning Nation's conflict. It focuses on the existing applications and

is geared to support seamless transition between peacetime and contingency operations. GCSS is therefore a critical component in supporting Command, Control, Communications, Computing and Intelligence Warrior (C4IFTW).

GCSS vision encompasses six essential attributes:

- Any box (computer) – is the result of Common Operating Environment (COE) to over come the incompatibility of different operating systems.
- Any authorized user – refers to the benefit of using common screens on any workstations to reduce training.
- One net – refers to the ultimate availability of all war fighter functions from a single workstation.
- One picture - refers to the capability to integrate information across functional areas, combat support, and command and control.
- Common services - include basic computing requirements such as printer, sound, and communication interfaces within the COE. Other common services include: forms and reports generators, database search and extraction tools and business process servers.
- Robust communications infrastructure - encompasses all of the networks, pipelines, and hardware necessary to provide global, near real-time access or situational awareness of information.
- Anywhere - means that we can access GCSS from any geographic location.

One of the first capabilities or applications to be made available via GCSS is asset visibility – the capability to provide users with timely and accurate information on the location, movement, status and identity of units, personnel, equipment and supplies. Presently, Joint Total Asset Visibility (JTAV) will incorporate some other key logistical functions of supply, maintenance and transportation and will be a very valuable tool for the war fighter.

A critical element of GCSS will be the ability to manage and manipulate data into a usable format for the war fighter. Joint Decision Support Tools (JDST) are computer tools and processes that will meet CINC and user requirements to plan, execute, monitor and plan logistics operations and provide a common operating picture of the battle space.

11.3.2 Summary on GCCS

GCSS merges with the Global Command and Control Systems (GCCS) where GCSS provides combatant commands and Joint Force Commanders (JFCs) the ability to provide military information rapidly to the National Command Authorities (NCA), as well as to the other supporting commands. Both GCSS and GCCS will provide Command and Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance for the Warfighter (C4ISFTW). Whereas GCCS concentrates heavily on operations, GCSS focuses on the combat support or logistical requirements of the warfighter. The convergence of both systems will provide situational awareness via a fused real-time, view of the battlespace for any

mission. GCSS results in near real-time command and control of the logistics pipeline; one fused picture of combat support to the warfighter, and a closed link between command and control and combat support during the execution of any operation or mission in support of the Joint Warfighter.

11.3.3 Summary on GCSS-MC

One of the components of DoD GCSS is the GCSS-MC. GCSS-MC is the information tool that provides logistics operators, planners and the warfighter, at the joint and Marine Corps levels, a fused, integrated, real-time, accurate logistics picture thereby enabling visibility into and control of the logisitcs pipeline. (Control is done through electronic collaboration visibility, use of joint decision support tools, and autonomous and real-time updates).

GCSS-MC includes only one server and associated peripherals. Navy Marine Corps Intranet (NMCI) provides connectivity of this equipement to the network for use by all authorized personnel with garrison. Components of GCSS-MC will reside on both the Non Secure Internet Protocol Router Network (NIPRNET) and the Secure Internet Protocol Router Network (SIPRNET) and they are unclassified.

(Note:There will be a one-way interface from the NIPRNET to the SIPRNET via a Guard interface. All transactional systems will reside only on NIPRNET. Some logistics, operational and planning data is classified. Some of the unclassified data aggregated becomes classified will reside on the SIPRNET).

11.3.4 Summary on GCSS-MC STRATEGY

The GCSS-MC Strategy is composed of three fundamental approaches:

- Management - Provides overall direction and alignment of the program and ensuring buy-in across the Marine Corps and DoD. Make necessary trade-offs between requirements, solutions and funding to ensure optimal results.
- Functional - Ensures both Warfighter and Service needs are refined into system and functional requirements and that the solutions are continually aligned with expectations amongst all stakeholders.
- Technical and System - Ensures a solution is implemented that meets the Warfighter and Service requirements within a best fit for the Marine Corps in terms of culture, economy, reliability, and robustness.

These three main approaches to the GCSS-MC strategy are intended to provide the Marine Corps and DoD with a product that satisfies warfighter needs within the desired schedule and to a satisfactory level of quality. These approaches are described in more detail below.

Management

Marine Corps Systems Command has empowered the GCSS-MC Management Team (GMT), with a chartered role to manage, plan, coordinate and synchronize

the overall GCSS-MC effort. The primary objective of the GMT is to ensure defined requirements supporting logistics transformation objectives identified by the Integrated Logistics Capability (ILC) analysis, and those requirements as mandated by the Department of Defense for GCSS implementation. The GMT is composed of Marine Corps Systems Command personnel and functional representatives and is committed to ensure the technical effort of GCSS-MC is aligned and tightly linked to the objectives and functional requirements of the Functional Advocates. A critical role of the GMT is to establish the ongoing communications with stakeholders to ensure all parties are engaged and committed to a common GCSS-MC goal.

The GMT will manage GCSS-MC as a portfolio of systems. Each system and related effort will be executed as a separate project. The theme is to provide central coordination and technical oversight, but to decentralize execution of the effort across managed projects and related efforts. To accomplish this, development will primarily follow a bottoms-up approach within the portfolio of systems and programs of record with each sub-team or sub-project executing their portions of the overall plan. The overall GCSS-MC plan will be elaborated over time with a top-down view using a rolling wave planning approach. Therefore, the near term plan will be developed in detail with future activities less detailed. As more information becomes known, the plan is elaborated. Generally, each current phase will have a detailed project plan and work-breakdown structure and the next phase of the plan will be in an elaboration state. The management approach will also work within the current framework of many concurrent parallel efforts and studies. The GMT will seek to integrate these activities into a cohesive program.

The strategy to achieve the GCSS-MC vision is based on actively maintaining a view of the desired end-state. This includes the planning and preparation to effectively build and operate the high availability, enterprise-level system and technical architecture necessary to provide a secure, global environment with an enterprise view of data able to provide near real-time information to the warfighter. The key is insuring establishment of well-managed systems and responsive services needed to provide the high level of confidence required by system users. Security planning is an integral up-front design process. The GMT will ensure GCSS-MC compliance through a series of synchronized planning and coordination activities focused on achieving the architected vision. The team will actively coordinate with technical organizations such as the Marine Corps PKI CAC programs, NMCI, PM Radio, and DISA, particularly in the areas of system requirements and security certifications. This activity will focus on information sharing related to common critical events that impact acquisition strategies and schedules or represent an increased degree of risk for dependent events and GCSS-MC development and fielding considerations. In addition, the GMT will strive to work with other organizations that may experience the enterprise-wide impact GCSS-MC will have as it is adopted by the logistics community.

Functional

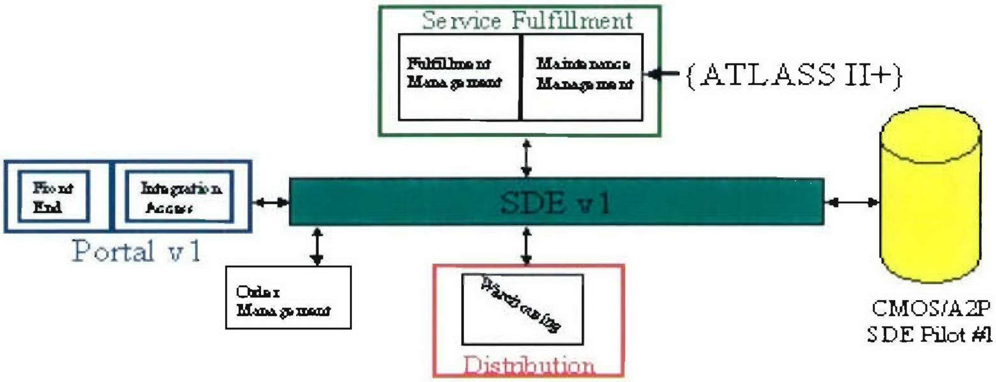

Figure 11.6: Framework - SDE

As GCSS-MC, is the physical Implementation of the ILC and the capability to meet CINC warfighter needs, the GCSS-MC team will be working closely with the ILC as re-engineers business processes. These are expected to yield direct benefits to the Marine Corps such as reduced customer wait time, reduced inventories. Indirectly, the process will result in trading MAGTF mass and footprint, for information and speed. A critical initial step of GCSS-MC will be translating requirements from the ILC into actionable system functional requirements. Similarly, selected CINC 129 requirements will be a Marine Corps responsibility and they will be assessed against current and planned systems and process capabilities. The effort will also include an activity to identify current Marine Corps portfolio gaps, and a Plan of Action and Milestones to meet those requirements through a variety of technical approaches. This includes the Shared Data Environment (SDE) [Figure 1.6], which represents a tool for meeting decision support and data access needs whose specific requirements require significant analysis and exploration.

A key tool in the functional strategy will be the use of pilot sites, ACTDs (Advanced Concept Technology Demonstration) and proofs of concept to generate, validate, and test the requirements and revised business processes. Where appropriate the GCSS-MC team will conduct metrics-based evaluation of programs of record versus other COTS and GOTS products for fit within the overall objective and to fill gaps. Recognized off-the-shelf capabilities will be evaluated as "buy" options for trade-off analysis against the "make" option, in the case where existing systems may require extensive rework or there is a clear gap in current system capabilities.

Technical and System Strategy

The GCSS-MC technical and system strategy is intended to ensure that systems, applications, and related technical infrastructure support the functional and system requirements of the ILC and DoD within affordability and supportability criteria as established by the Functional Advocates. The result will be an architecture comprising Systems, Operational and Technical views that best meet the Marine

Corps' objectives and culture. This objective can be described broadly as a family of systems that:

- Is a fully secure, networked infrastructure
- Provides high availability and managed services
- Provides users a common access methodology (CAC – Common Access Card, Portals)
- Contains common, consistent, accurate, current accessible data (Shared Data Environment)
- Is available to users through web browsers (web-enabled or web-based)
- Builds upon an application layer (business logic) separate from the data layer (database)
- Utilizes Automated Identification Technologies (AIT) to support data capture (Asset visibility)
- Adheres to data and technical standards (DoD, DII COE, data standards, ANSI, ISO)
- Supports near real-time logistics C2.

To meet this objective, the approach to be pursued for all technical activities will consist of engineering studies and trade-off analyses coupled with pilots, proofs of concept, and modeling and simulation activities, where applicable. The first step will be to translate the business and higher-level DoD GCSS requirements into specifications that are compatible with systems design requirements. Additional analysis will be required to identify types and quantities of business transactions. These will be translated into system stress and volume requirements, which will impact server and network requirements. That, coupled with an assessment of current and planned architectural capabilities, topologies and limitations, will allow for a balanced evaluation of various technical approaches. These activities are clearly necessary when addressing large-scale enterprise systems and near real-time sharing of data. These approaches will evolve into one, or a combination, of the following technical architectural solutions:

- Development of Enterprise Integration Portals or a hierarchical family of portals
- Development of new, custom systems or migration of legacy systems to web-based enterprise systems
- Web-enabling of current systems
- Communication of data through message-oriented middleware
- Integration of disparate databases into single instances (through packaged or custom applications)
- Use of publish/subscribe methodologies using data warehousing or other technologies
- Integration of Automated Identification Technologies (AIT)
- Identification and use of other technologies as identified and appropriate

The systems and architectures developed will be interoperable through adherence to:

- Technical standards within the Marine Corps and the portfolio of systems
- Standardization of key business data and coordination with DoD data standardization programs
- Use of external Service and Agency systems, methodologies and tools as appropriate to satisfy Marine Corps requirements
- Adherence to all relevant standards

Critical to the success of GCSS-MC is the secure, network infrastructure to support the network-centric applications of the future. This applies equally to garrison and deployed operations. The GMT will work closely with PM NMCI and PM Radio to ensure that requirements are effectively developed and described as they impact the network and will work together to engineer viable mid and long range solutions for GCSS-MC.

11.3.5 GCSS-MC Process Summary

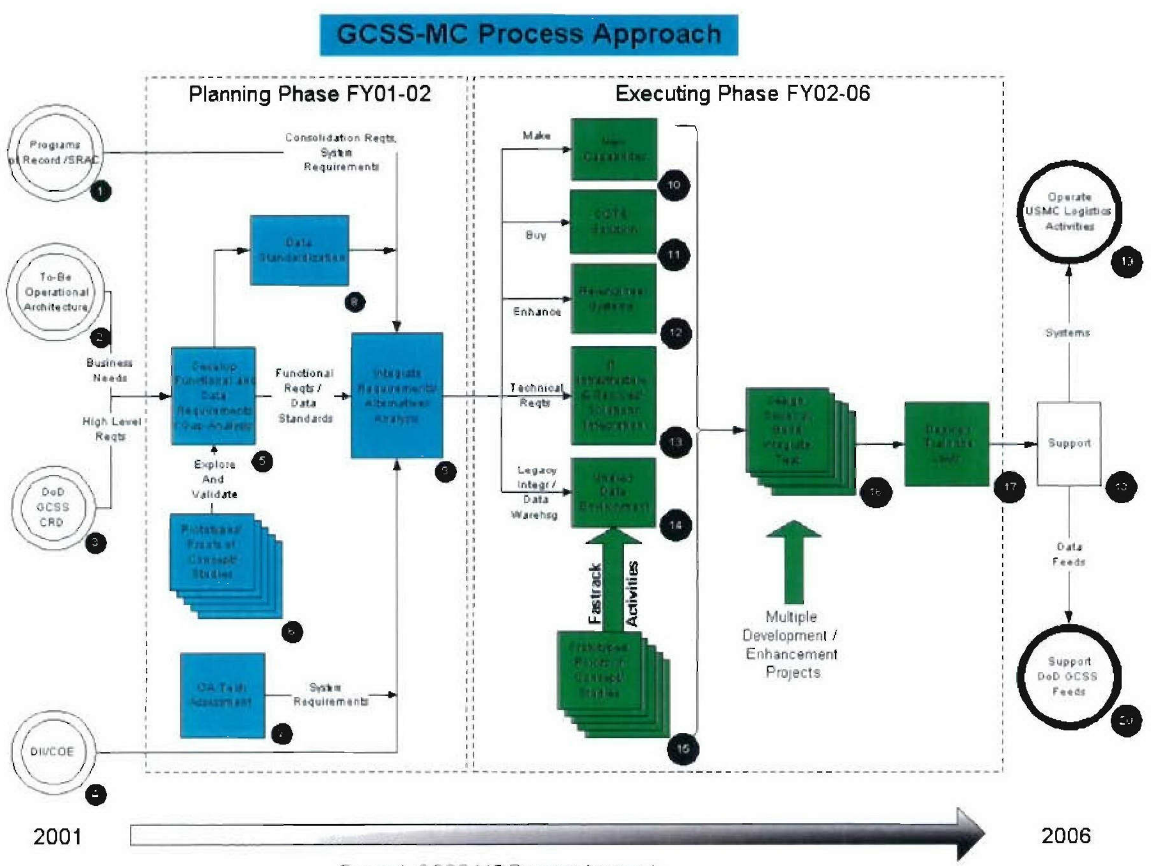

Figure 1 GCSS-MC Process Approach

Figure 11.7: GCSS-MC Process

The key to achieving GCSS-MC will be the synchronization and alignment of the many organizations and efforts ongoing into a cohesive process with a process view. Only a documented process can ensure that all the steps in the program are addressed and coordinated. The below mentioned four phases are depicted in Figure11.7.

There are four main phases in the process:

1. GCSS-MC feeds, which are the primary inputs to the GCSS-MC process such as CINC and Service requirements, revised business processes and policies, and architecture considerations.

2. Planning, in which all inputs are processed into requirements and technical considerations and during which the execution phase of the project, is planned in detail.

3. Execution, during which GCSS-MC is implemented and deployed.

4. Operations, during which the family-of-systems is employed and supported.

The phases will overlap each other and the final implementation may be versioned over several years, however, the notional process is basically unchanged.

Starting with

1. The Programs of Record form a baseline of what the USMC has today. These systems will undergo the Systems Realignment and Categorization (SRAC) process. Many current systems will be eliminated as a result of this analysis. From the remaining systems will be selected systems for inclusion in the GCSS-MC portfolio. These systems will be selected based on support for ILC and CINC requirements. The portfolio will drive the gap analysis and the alternative solution sets.

2. The main output will be operational architecture artifacts. These will formally present requirements at a "business need" level or lower level of detail and will be considered critical input.

3. These and other DoD and commercial standards form the constraints for constructing the technical and system solutions.

4. The DII/COE is the Defense Information Infrastructure / Common Operating Environment.

The above 4 activities are outside, but interdependent of the scope of the GMT in GCSS-MC. These activities feed into the Planning phase of GCSS-MC, which is a requirements exploration and development phase, but also includes all management and planning activities to prepare for the execution of the GCSS-MC project.

The To-be OA and the GCSS CRD are the primary inputs to the Requirements process

5. This major process involves developing system requirements and specifications in the functional domains and identifying gaps in the current capabilities to meet those requirements. Many requirements will be discovered or validated during the many pilot and proof of concept programs that are currently ongoing

6. These activities are independent and largely uncoordinated, however, they will be integrated into the GCSS-MC process as they are discovered and appraised for adding value to the program. Other requirements will be discovered through concept and trade studies, such as capabilities that are available in commercial software packages.

7. The Operational Architecture Technical Assessment 7 will determine the technical capability and gaps of the current and projected architectures to support the functional and technical requirements for GCSS-MC. The results of this activity will be integrated with all discovered requirements and used as input to the alternatives analysis.

8. The Data Standardization effort 8 will perform the logical data modeling to ensure that GCSS-MC is easily interoperable and oriented towards a shared, integrated data environment. This effort works concurrently with the development of data requirements in process 5 and feeds into the requirements integration and solutions analysis activity 9.

9. While activity 5 is oriented towards capturing requirements, the requirements integration activity 9 is oriented towards integrating them and developing the specifications for moving forward and assessing solutions applicable to the problem domains. In this phase, all requirements are brought together and solution alternatives are investigated. The result is a body of knowledge sufficient to develop detailed plans, estimates and costs for specific systems and technical solutions to be implemented in the Execution Phase. This activity will include additional studies and analysis to present alternatives and make decisions about the future. These studies will include business case assessments to weigh project phasing and trade-offs on return on investment between make or buy solutions. It is expected that there will be overlap between planning and execution, as some capabilities will be implemented later than other higher priority functions.

10. From solutions analysis, GCSS-MC moves into the execution phase where the solutions are implemented. There will be a combination of five types of solutions: make 10, where new systems are custom built to achieve desired capabilities;

11. By 11, where commercial packages or tools are purchased to leverage commercial capabilities into the Marine Corps;

12. Enhance 12, where existing programs of record are re-engineered or otherwise enhanced to leverage existing capabilities;

13. Information technology infrastructure 13, where IT solutions are designed and built to support the required services; and legacy systems integration and

14. Data-warehousing applications 14 are constructed to provide a platform for a shared data environment. As these solutions are being implemented, existing and proven pilots and other

15. Prototypes 15 may be integrated into the solution sets as an additional alternative. Like the pilots in activity 6, they will be taken as targets of opportunity for adding value.

16. As the approach of GCSS-MC is a "bottoms-up" approach, each solution will be implemented as a separate project 16 with a project manager/officer overseeing the specific activity.

17. These individual efforts will be coordinated and supported centrally by the GMT acting as a Project Management Office operating with authority from the Program Manager. As the projects are completed, they will be integrated into the overall implemented solution.

18. They will be deployed in a phased manner 17.

19. The support activity 18 will be growing as more functions and capabilities are implemented within GCSS-MC. The core infrastructure will be built as one of the first projects to be implemented in 19.

20. The support activity includes operations and application support and maintenance as well as an enterprise helps desk function.

    As it operates, GCSS-MC, as the physical implementation of the ILC, will support both logistics real-time operations 19 and GCSS 20.

11.3.6 Summary on Autonomic Logistics

Autonomic Logistics (AL) is a concept which is supposed to follow the following facts: using advanced IT systems to support military command structure with real or near-real time information on the status of weapons and support systems deployed to the battle space or other area of operations.

The main motivation is: currently mission critical data on weapon and support systems is communicated from the battlefield through manual methods, which causes: Reporting burden on the commander; Data is generally inaccurate and/or lacks granularity; Not timely – up to 24 hours old; And because of these information delay, the current logistic system is inefficient with respect to inventory utilization, readiness rate, etc. But AL is expected to overcome these shortcomings and bring reduced spares inventories, higher readiness rates and overall reduced logistics footprint.

Based on the study of current weapon and support system and experience from available military AL applications such as Joint Strike Fighter (JSF) AutoLog, and future weapon and support system will operate in AL environment that should have the following key system components:

1. Ground Equipment which encompasses both diagnostic and prognostic capability supported by Health Management system aboard;
2. Technically supporting and operational personnel;
3. An advanced Information System characterized with Wireless communication technology and Integrated Data Environment (IDE) and Shared Data Environment (SDE);
4. A logistic infrastructure that will be responsive to support requirements.

Currently, there are similar systems or concept existing in both military and commercial field. In military field, there are: COMTECH Mobile Datacom, U.S. army Advanced Diagnostics Improvement Program, PLRS, JSF Autonomic Logistics, Weapon System Support Platform Based Readiness, etc. In commercial field, there are: OmniTRACS, ONSTAR and Low jack. Doing research in these similar systems or concept may help us to have clearer picture about AL in our framework.

11.4 References

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[6] http://www.bbn.com/lpds/lea.html
[7] http://www.mstp.quantico.usmc.mil/FuncAssess/faMain.asp
[8] http://www.hqmc.usmc.mil/ilweb.nsf/0/89c695b6f9d1ee3185256974004d66bc/$FILE/LPI+trifold.pdf
[9] http://www.sapient.com/case/usmc.htm
[10] http://www.matcom.usmc.mil/ilcbriefs/files/ILCOpsArchOvrvw.ppt

[11]
http://www.ala.usmc.mil/secrep/files/Briefings/Higher%20HQs/ILC%20ESC%20PRESENTATION%20%2019%20Dec%20Ver%202.PPT
[12] http://www.dla.mil/jgwi/docs/GCSS12Jan00.pdf
[13] http://www.dtic.mil/ndia/2003interop/Leon.pdf
[14]
http://www.hqmc.usmc.mil/LP.nsf/18aee9e39b739b28852569dc0061a4c4/210f900ade12b5b185256c14005bbc81/$FILE/GCSS-MC+Update+v3.ppt
[15] http://www.gcss-mc.info (really an interesting one!!! With more information)
[16] http://www.dtic.mil/jcs/j4/projects/gcss/gcssbrochure/brochure.htm
[17]
http://www.hqmc.usmc.mil/LPI.nsf/0/93ebe3de3ebbcd0d85256a480041648b?OpenDocument
[18] http://www.dodait.com/conf/ipt/0503/MCRackhamGCSS.ppt
[19]
http://www.hqmc.usmc.mil/LPI.nsf/0/0e5fb958fb869ece8525698b006e37e9?OpenDocument
[20] http://www.matcom.usmc.mil/ilcbriefs/files/GCSS.ppt
[21] http://www.dtic.mil/jcs/j4/projects/tav/15aug02usmcbrief.ppt
[22] Lt. Col. Ruark, Bob; "Operational Architecture"CD; July '03

11.4 Appendix: 2 – URLs for Condition based maintenance

The following websites give detailed information on different aspects of CBM, from Commercial DoD and Research Views.

Accurate Automation Corporation	http://www.accurate-automation.com/
Adaptics, Inc.	http://adaptics.com/
Alexis Logic Corporation	http://www.alexis.com/alc.html
ALPHATECH, Inc.	http://www.alphatech.com/
Augusta Technology	http://www.augusta.co.uk/aboutaug.htm
BEASY	http://www.beasy.com/
BPC International Inc.	http://www.tfa2.com/bpc/
BRETECH ENGINEERING LTD	http://www.bretech.com/
C & S Group Pty. Ltd.	http://interdomain.net.au/~csgroup/
Cadick Corporation	http://www.electricnet.com/cadick/cndbased.htm
China Steel Corporation	http://www.csc.com.tw/
Computational Systems Inc.	http://www.compsys.com/
CranePartner International	http://www.cranepartner.com/
Danaos Maritime Services	http://193.92.153.1/
Dingo Maintenance Systems	http://www.rollanet.org/~dingo/
DLI Engineering Corporation	http://www.DLIenginerring.com/
Dofasco Inc.	http://www.dofasco.ca/
Dyal Associates	http://www.fc.net/~dyal/
DYNAMIC INSTRUMENTS	http://www.dynamicinst.com/

Electricity Generation Authority of Thailand	http://www.egat.or.th/
Engineering Mechanics Technology, Inc.	http://www.emtinc.com/
Entek IRD International Corporation	http://www.entek.com/
Environment One Corporation	http://www.eone.com/eone/
Equitronics	http://www.equitronics.com/
ERA Technology Ltd.	http://www.era.co.uk/
EXSYS, Inc.	http://www.exsysinfo.com/
Failure Analysis Associates, Inc.	http://www.fail.com/
Field Diagnostic Services, Inc.	http://www.ies.laf.in.us/acrx/
GasTOPS, Ltd.	http://www.gastops.com/
GDE Systems, Inc.	http://www.gdesystems.com/
Gensym Corporation	http://www.gensym.com/
Geotest, Inc.	http://www.geotestinc.com/
Hardy Instruments	http://www.hardyinst.com/index.html
Hartford Steam Boiler	http://www.hsb.com/
Hathaway Power Instrumentation	http://www.hathaway-systems.com/
Honeywell Technology Center	http://www.htc.honeywell.com/
IDAX Incorporated	http://www.idax.com/
Innovative Software Designs	http://www.innovsw.com/
Inteltech Enterprises, Inc	http://www.inteltek.com/
International Submarine	http://www.ise.bc.ca/

Engineering, Ltd.	
IVO Transmission Services Ltd. (IVS)	http://www.ivo.fi/ivswww/e_home.htm
KAUKO Condition Monitoring Ltd.	http://kaukomarkkinat.fi/kcm/
KETRON Division, The Bionetics Corporation	http://www.ketron.com
Knowledge Industries	http://www.kic.com/
LG Group	http://www.lg.co.kr/
Liberty Technologies	http://www.libertytech.com/
Life Cycle Engineering, Inc. (LCE)	http://www.lce.com/
Machinery Condition Monitoring Inc.	http://www.highres.nb.ca/mcminc/index.html
MacNeal-Schwendler Corporation	http://www.macsch.com/
Maintenance and Diagnostics, LLC	http://www.tncnet.com/~MandD/
MARINTEK	http://mt1.marintek.sintef.no/
Material Integrity Solutions, Inc.	http://www.misolution.com/
Monition Ltd. (International)	http://www.monition.com/
National Instruments	http://www.natinst.com/
Novadyne	http://www.ncsi.com/
PdMA Corporation	http://www.pdma.com/
Powertech Labs Inc.	http://web.ucs.ubc.ca/bchydro/powertech/default.html
Predictive Maintenance	http://iquest.com/~pmi/

Inspection, Inc.	
PRUFTECHNIK AG	http://www.pruftechnik.com/
PSDI	http://www.psdi.com/
Randle, Inc.	http://www.cquest.com/chaos.html
Reliability Center, Inc.	http://www.reliability.com/
Revere	http://www.revereinc.com/
Rockwell International	http://www.rockwell.com/
Sargent Controls & Aerospace	http://www.sargentcontrols.com/
SKF Condition Monitoring	http://www.skfcm.com/
SKM Systems Analysis, Inc.	http://www.skm.com/afault.html
Solartron Instruments	http://www.solartron.com/index.htm
Tracor Applied Sciences, Inc.	http://www.aard.tracor.com/home/
Triant Technologies Inc.	http://www.triant.com/
TSW International, Inc	http://www.tswi.com/index.html
UE systems, Inc.	http://www.uesystems.com/
Vetronix Corporation	http://www.vetronix.com/
Vibrant Technology, Inc	http://www.vibetech.com/
Vibration Measurement Technology Ltd.	http://www.jsp.fi/vmt/vmt2945.htm
Vibration Specialty Corporation	http://www.iliad.com/vib/default.html
VibroAcoustical Systems and Technologies, Inc	http://www.inteltek.com/

11.5 Appendix: 3 – Autonomic Logistics (AL) on Joint Strike Fighter (JSF)

11.5.1 Overview on JSF AL

The JSF AL is a new system that will enable the aircraft to function throughout the life of the platform with low costs when compared with the legacy systems. AL is a concept, which will automate the aircraft logistics with very less human intervention. JSF actions that will support this concept include maintenance scheduling, flight scheduling, order spare parts etc.

AL encompasses four key features to provide a comprehensive logistics support for the JSF and they are as follows:

1. Prognostics and Health Management (PHM)
2. Joint Distributed Information System (JDIS)
3. Technologically Enabled Maintainer
4. Advanced Logistics Infrastructure

JSF Prognostics and Health Management concept is the corner stone of Autonomic Logistics. The PHM provides data information and the knowledge for initiating the Autolog chain.

The below mentioned are the capabilities of the PHM:
1. Enhance flight safety
2. Improve efficiency of the logistics chain
3. Allow scheduling of logistics events to compliment operational planning

The proposed architecture for the PHM includes a hierarchical approach. In brief, the PHM begins by collecting the data at the sensor level and transmits it to the area reasoners, who will turn this data into information for a specific subsystem. This system, by design is envisioned to provide valuable information and an intelligent warfighter.

The key aspect of the PHM is the usage of minimum number of specialized sensors used as area managers. By definition, area managers contains software reasoners or software modules in which data from various sources is fused together by means of fuzzy logic, neural networks, data fusion, model and case based reasoning, trends to detect faulty parts and anomalies.

The concept behind the PHM is not to overload the warfighter with a large number of sensors, which tend to fail and also induce ambiguity when detecting part failures.

Each area manager monitors a particular subsystem of the warfighter i.e. area managers for propulsion, structures, vehicle management system and mission systems. With its own software algorithms and computing capabilities, the area manager analyzes the signals automatically from the sensors and other data sources to determine whether the part or a component of a specific subsystem exhibits characteristic that may lead to failure. Information collected by the area managers is then transmitted to a single air vehicle manager for further information fusion and elimination of ambiguities. The single air vehicle manager later filters information and sends certain information to the pilot for his use and the rest is conveyed to the maintenance personnel for his action.

The significance of the JSF software architecture is to minimize ambiguities and its purpose is as follows:

1. It allows the diagnostic system to perform more functions without the introduction of abundant number of specialized sensors. It is the job of the software architecture to convert this data into actual information for maintenance.
2. By fusing data from various sources, anomalies can be crosschecked with information from other subsystems in order to avoid false alarms. All sensor information will be validated in the area and single air vehicle manager level with other sensor data or aircraft parameters to verify the fault.

Data filtering is accomplished by employing a new technology called "coherence analysis" that detects components performance anomalies.

Another aspect of the PHM is to perform many of the prognostic calculations, remaining useful life calculations, cycle counting, and lifeing of components. This processed information together with the rest of the information from the single air vehicle is transmitted to the JDIS to inform the supply chain what it has to do to maintain the airplane fully operational. The metric to be used is probability of failure within a specified number of flight hours. The aim of the JSF prognostics system is to have an estimate of remaining useful life of a component in a warfighter at any given time. Prognostics will also allow a lead-time for the logistics pipeline to get parts and to educate the maintainers to change those parts.

Another significant aspect of Autonomic Logistics is "part tracking". With AL, all component parts will be tracked by serial number across all aircraft tail numbers. For example, if a set of new bearings were not performing up to its standard, then JDIS would be able to identify all bearings from the given shipment and their locations and pull them before the start to fail while in operation. This will avoid in ground the entire fleet in order to check all bearing on all aircraft to identify the faulty ones.

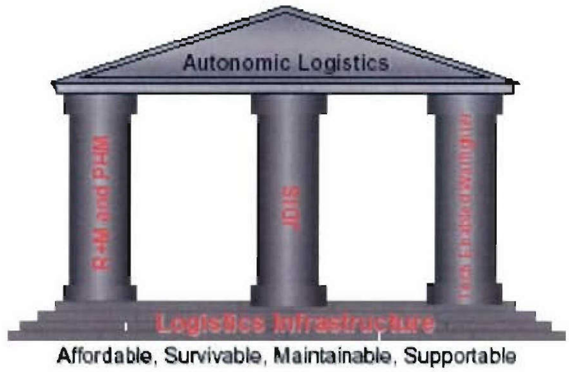

Figure 11.8: Features of JSF AL

Joint Distributed Information Systems (JDIS):

The "backbone" of AL is JDIS and will provide distributed information system to integrate PHM supplied data and information to all the other necessary maintenance management, logistics, supply, OEM, mission planning etc. JDIS provides the passage that would take the prognostic and diagnostic information transmitted by the aircraft and determines from it the manpower numbers, capabilities and training requirements to complete the necessary tasks. Some of the tasks that will be performed either automatically or integrated with JDIS are as follows:

- ⇒ Mission planning
- ⇒ Maintenance action scheduling
- ⇒ Ordering of spare parts
- ⇒ Scheduling of flight and maintenance training
- ⇒ Assignment of specific plots to specific missions based upon experience and readiness
- ⇒ Assigning specific aircraft to specific missions based upon aircraft availability and capability
- ⇒ Storing maintenance, training, spare part, and logistic information in the database warehouse

It has to be noted that all these tasks are performed automatically; at any given time, a person with the necessary authority can access the system and make changes as required.

The information fusion capability of the PHM system will allow JDIS to output and pass on actions and recommendations rather than just data. These support decision tools will include: maintenance information, supply chain management, health and usage information, training management, and recommendations regarding best use of resources.

Technologically Enabled Maintainer
The maintainer in the AL concept has the full set of modern, technologically capable and appropriate tools to act efficiently and promptly when called for immediate maintenance duty. The tool sets include: comprehensive knowledge of the actual aircraft health before beginning work (PHM and JDIS), appropriate and timely training to conduct the task (prognostics lead time, prior training methods), and interactive guidance available in real time to provide supplementary information when required.

It is important to note that the logistics and PHM should have minimal human intervention.

Due to its autonomic nature, the tasks assigned to the maintainer should be transparent and must be presented in the manner that provides proper procedures, safety, detail appropriate to skill level, rehearsal/review of the task when requested, tools and parts required and quality and assurance.

Advanced Logistics Infrastructure
The information obtained from PHM and JDIS are of no avail if the logistics infrastructure is not flexible and responsive enough to generate the necessary support in the right place when required. Some of the issues to be tackled to have the appropriate infrastructure are the levels of maintenance, Inventory Policies, and supply chain management.

11.6 References

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[7] http://log.dau.mil/papers/research/apmc%202000/schnepp.doc
[8] http://log.dau.mil/papers/research/apmc%202000/fitch.doc
[9] http://www.jsf.mil/Program/Briefings/JSF%20Program%20Brief%2012_02.pdf

11.6 Appendix: 4 – Sensor Processing

11.6.1 Sensors

11.6.1.1 Transducers

Sensors and actuators can both be *transducers*. A transducer is a device that converts input energy of one form into output energy of another form. For example, a microphone is a sensor that converts sound energy (in the form of pressure) into electrical energy, while a loudspeaker is an actuator that converts electrical energy into sound energy.

11.6.1.2 Classical Integrated Sensor

A Sensor is a device, which is designed to acquire information from an object and transform it into an electrical signal. A classical integrated sensor can be divided into four parts as shown in Figure 11.9.

Figure 11.9 shows the notion of classical integrated sensors. The first block is sensing element (for example, resistor, capacitor, transistor, piezo-electric material, photodiode, resistive bridge, etc). The signal produced from the sensing element itself is often influenced by noise or interference. Therefore, signal-conditioning and signal-processing techniques such as amplification, linearization, compensation and filtering are necessary (second block) to reduce sensor non-idealities.

In case of data acquisition, the signal from the sensor must be in a serial or parallel digital format. This function can be realized by the analog-to-digital or frequency-to-digital converter. The last block is a sensor-bus interface [2].

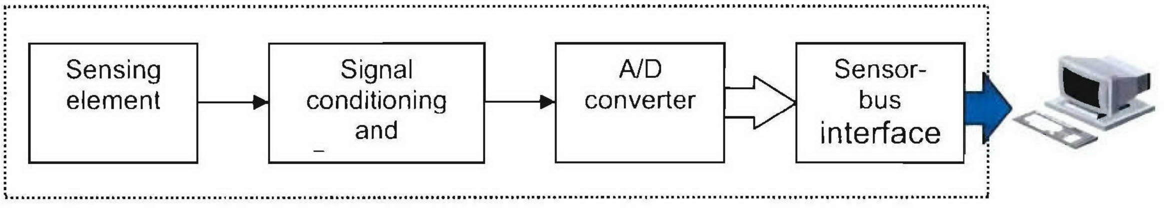


Figure 11.9: Classical integrated sensors

11.6.1.3 Smart Sensor

A Smart sensor block diagram is shown in Figure 11.10. A microcontroller (μK) is typically used for digital signal processing (for example, digital filtering), analog-to-digital or frequency-to-code conversions, calculations and interfacing functions.

Microcontrollers can be combined or equipped with standard interface circuits. Many microcontrollers include the two-wire I^2C bus interface, which is suited for communication over short distances (several metres) or the serial interface RS-232/485 for communication over relatively long distances.

However, the essential difference of the smart sensor from the integrated sensor with embedded data-processing circuitry is its intelligence capabilities (self-diagnostics, self-identification or self-adaptation (decision making)) functions. As a rule, these functions are implemented due to a built-in microcontroler (microcontroller core ('microcontroller like' ASCI) or application-specific instruction processor (ASIP)) or DSP. New functions and the potential to modify its performance are the main advantages of smart sensors. Due to smart sensor adaptability the measuring process can be optimized for maximum accuracy, speed and power consumption. Sometimes 'smart sensors' are called 'intelligent transducers' [2].

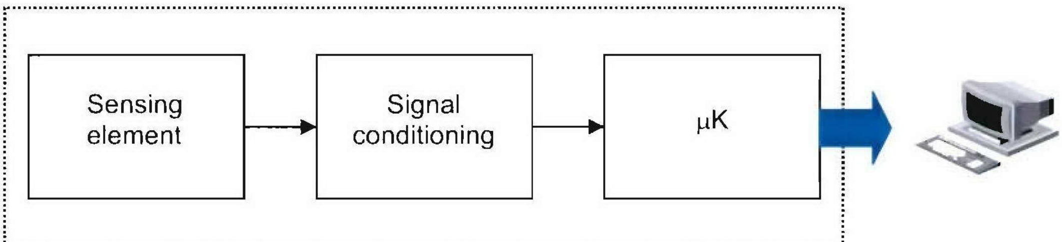


Figure 11.10: Smart sensor

11.6.1.4 Sensors

A sensor converts the physical phenomena of interest into a signal that is input into your data acquisition hardware. There are two main types of sensors based on the output they produce: digital sensors and analog sensors.

Digital sensors produce an output signal that is a digital representation of the input signal, and has discrete values of magnitude measured at discrete points in time. A digital sensor must output logic levels that are compatible with the digital receiver. Some standard logic levels include transistor-transistor logic (TTL) and emitter-coupled logic (ECL). Examples of digital sensors include switches and position encoders.

Analog sensors produce an output signal that is directly proportional to the input signal, and is continuous in both magnitude and in time. Most physical variables such as temperature, pressure, and acceleration are continuous in nature and are readily measured with an analog sensor. For example, the temperature of an automobile cooling system and the acceleration produced by a child on a swing all vary continuously.

The sensor you use depends on the phenomena you are measuring. Some common analog sensors and the physical variables they measure are listed below.

Common Analog Sensors

Sensor	Physical Variable
Accelerometer	Acceleration
Microphone	Pressure
Pressure gauge	Pressure
Resistance temperature device (RTD)	Temperature
Strain gauge	Force
Thermocouple	Temperature

Table 11.1: Common Sensors and physical variables

11.6.2 Signal Conditioning

Sensor signals are often incompatible with data acquisition hardware. To overcome this incompatibility, the sensor signal must be conditioned. The type of signal conditioning required depends on the sensor you are using [1]. For example, a signal might have a small amplitude and require amplification, or it might contain unwanted frequency components and require filtering. Common ways to condition signals include

- Amplification
- Filtering
- Electrical isolation
- Multiplexing
- Excitation Source

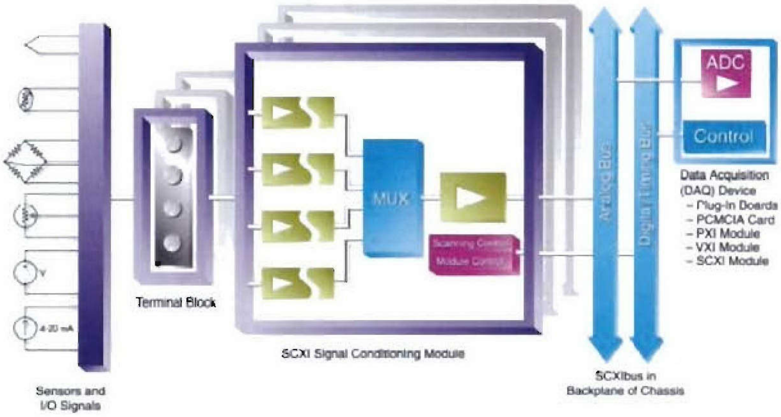


Figure 11.11: Overall scheme of signal conditioning

11.6.2.1 Amplification

Because real-world signals are often very small in magnitude, signal conditioning can improve the accuracy of data. Amplifiers boost the level of the input signal to better match the range of the analog-to-digital converter (ADC), thus increasing the resolution and sensitivity of the measurement. While many Data Acquisition devices include onboard amplifiers for this reason, many transducers, such a thermocouples, require additional amplification.

11.6.2.2 Attenuation

Attenuation is the opposite of amplification. It is necessary when the voltages to be digitized are beyond the input range of the digitizer. This form of signal conditioning diminishes the amplitude of the input signal so that the conditioned signal is within range of the ADC. Attenuation is necessary for measuring high voltages.

11.6.2.3 Filtering

Filtering removes unwanted noise from the signal of interest. Additionally, signal conditioners can include filters to reject unwanted noise within a certain frequency range. Almost all DAQ applications are subject to some level of 50 or 60 Hz noise picked up from power lines or machinery. Therefore, most conditioners include lowpass filters designed specifically to provide maximum rejection of 50 to 60Hz noise.

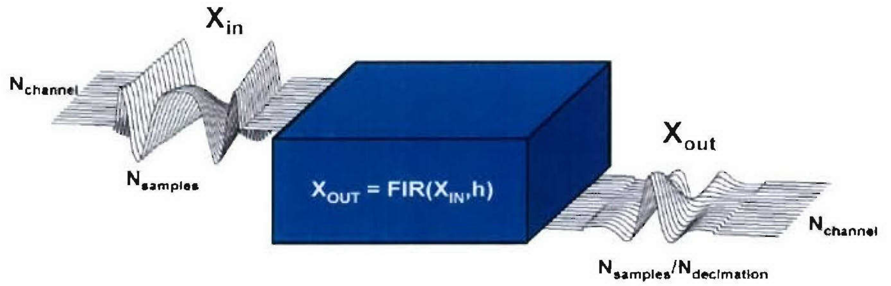


Figure 11.12: Filtering

11.6.2.4 Electrical Isolation

If the signal of interest contains high-voltage transients that could damage the computer, then the sensor signals should be electrically isolated from the computer for safety purposes.

Improper grounding of the system is one of the most common causes for measurement problems, including noise and damaged measurement devices. Signal conditioners with isolation can prevent most of these problems.

11.6.2.5 Multiplexing

A common technique for measuring several signals with a single measuring device is multiplexing. Typically, the digitizer is the most expensive part of a data acquisition system. By multiplexing, you can sequentially route a number of signals into a single digitizer, thus achieving a cost-effective way to greatly expand the signal count of your system. Multiplexing is necessary for any high-channel-count application.

11.6.2.6 Excitation Source

Some sensors require an excitation source to operate. For example, strain gauges, and resistive temperature devices (RTDs) require external voltage or current excitation. Signal conditioning modules for these sensors usually provide the necessary excitation. RTD measurements are usually made with a current source that converts the variation in resistance to a measurable voltage.
As show in Figure 11.13, there is the process of intelligent diagnosis and prognosis system [5].

11.6.3 Signal Processing

11.6.3.1 Signals

Signals commonly need to be processed in a variety of ways. For example, the output signal from a transducer may well be contaminated with unwanted electrical "noise". The signal is often strongly affected by "mains pickup" due to electrical interference from the mains supply. Processing the signal using a filter circuit can remove or at least reduce the unwanted part of the signal. Increasingly nowadays the filtering of signals to improve signal quality or to extract important information is done by DSP techniques rather than by analog electronics.

11.6.3.2 Digital Signal Processing

According to Texas Instruments digital signal processing is defined as ' The science concerned with representation of signals by sequences of numbers and the subsequent processing of these number sequence'. Processing involves either extracting certain parameters from a signal or transforming it into a form that is more applicable. The digital implementation of signal processing has several advantages:

- It is possible to accomplish many tasks inexpensively that would be either difficult or impossible in the analog domain, for example, Fourier transforms.
- Digital systems are insensitive to environmental changes and component tolerances and ensure predictability and repeatability.
- Reprogrammability features.

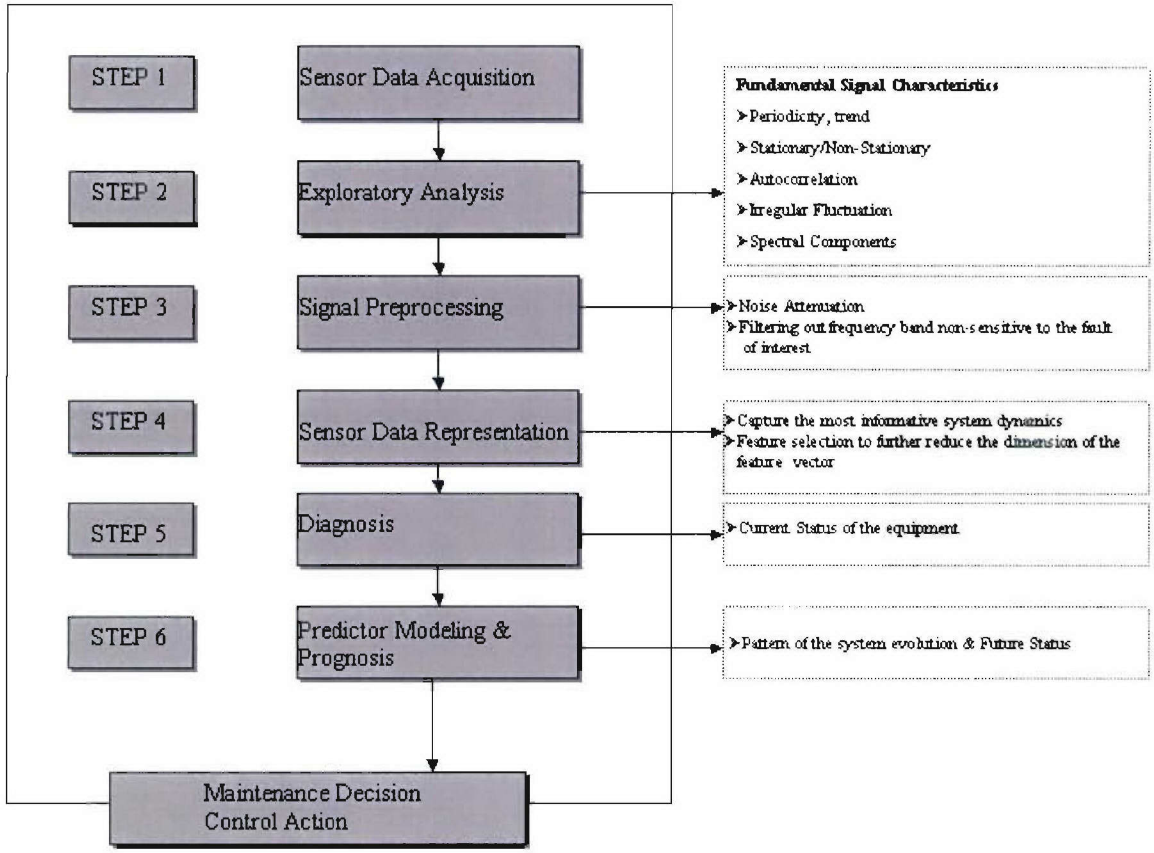


Figure 11.13: Schematic Diagram of Intelligent Diagnosis and Prognosis System

11.6.4 Vehicle Fault Diagnostic

Fault Diagnosis can be generally defined as the process that identifies the root cause of a failure. Vehicle level fault diagnostic should be considered an important area of study for several reasons, including the following:

- Failure diagnosis adds directly to the cost of vehicle parts – software is not "free" and warranty part returns cost money.
- Failure diagnosis is a large contributor to the labor time involved in vehicle servicing – once a problem is identified, a solution is typically swift.
- Improper fault diagnosis can lead to an incorrect repair action – this leads to opportunity costs and fosters the perpetuation of inefficient problem solving (unsatisfied customers tend not to return)

There are several levels of vehicle diagnostics. The first level of diagnostics may be a simple reminder to the driver that standard maintenance (i.e., replacing filters and fluids) is required. The next level of diagnostics is targeted for the service

technician, using more sophisticated tools and techniques. And, there is a level or levels of tools and methods used by the system architects and engineers who develop the sub-system hardware and software. A well-planned diagnostic strategy fully comprehends the relationships between these levels [3].

11.6.5 Sensor Fusion

In the case of multiple sensor faults, highly interactive components or subsystems, information from a single sensor does not provide enough intelligence to accurately diagnose all of the possible faults. A better approach is to exploit the use of multiple sensors to provide additional information to the diagnostic algorithm. Using the approach, observers can be selected such that they provide complementary and/or redundant information about the component or subsystem behavior. The additional information provided by this scheme can be used to broaden the number and scope of potential faults that the diagnostic algorithm detects and reduces the probability of misdiagnosing a failure.

Fusing two raw signals together and processing the resulting information, improved characterization of the input signals can be obtained. Further, by combining a number of fused input signals with a simple voting or decision making algorithm, improvements in fault classification accuracy can also be obtained [3].

11.6.6 LAV Diagnostic

11.6.6.1 LAV Condition Monitoring Defined

LAV Condition Monitoring (LCM) systems that we'll discuss in this project refer to computer-based tools for maintenance and process control related to industrial machinery. Such setups can assist with:

- Repair / Rebuild Decisions
- Process Control and Optimization

One-way of classifying LCM systems are as either continuous or periodic, based on when and how monitoring is performed. Continuous monitoring systems are commonly attached to the machine of interest. Periodic monitoring systems are often portable and are used on multiple machines. Although we'll focus on continuous monitoring in this project, much of the information will also apply to periodic monitoring [1].

11.6.6.2 LCM System Elements

A good place to start is with an overview of the components of a LAV conditioning monitoring system. These include:

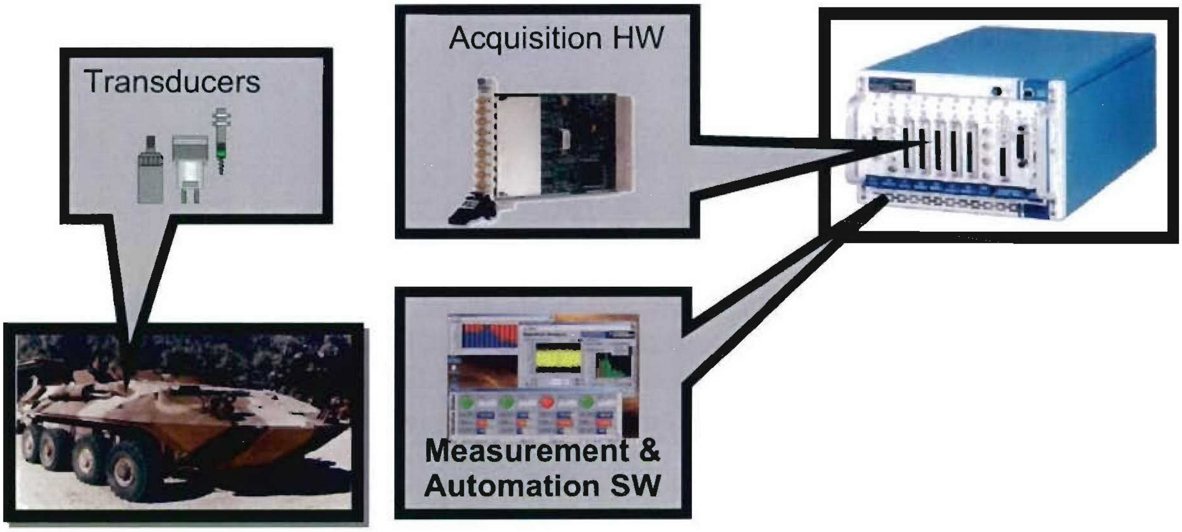


Figure 11.14: LCM Components

- The first component is the LAV that you intend to monitor.
- Transducers such as accelerometers, proximity probes, and thermocouples convert machine-generated signals such as sound, vibration, temperature, pressure, power consumption and others into a measurable voltage.
- Cabling and perhaps signal conditioning hardware connect your transducers to a measurement instrument.
- The measurement instrument here is a standard PC. As we'll see, this offers a number of benefits.
- Installed hardware and software converts the PC into a measurement instrument.
- Acquisition hardware in the form of plug-in PCI or CompactPCI/PXI card or cards can provide signal conditioning and converts the sensor output to a computer-friendly form.
- Software for measurement and automation controls our acquisition hardware, provides a monitor-site man/machine interface (MMI), and interprets acquired signals for monitoring and to assist diagnosis. It can also provide functions such as signal interpretation, report generation, and data sharing using wireless.

11.6.6.3 LCM-Relevant Information

In planning a custom machine condition monitoring system, it's useful to consider some of the potential sources of information that could be monitored. LCM-related information can be either:

- Fixed / known (machine design, machine health history)
- Vary with time (operating environment, operating conditions, operating parameters, and machine health)

The acquisition portion of LCM system will focus on the varying information. Measurable: temperature, pressure, vibration, power, flow, and many others. Acquiring signals such as temperature, pressure, vibration, power, flow, and perhaps others is only the first step; effective monitoring systems rely on an association of available information with the machine characteristics of interest. The analysis portion of LCM system will process measured data and analyze it in conjunction with other known information such as machine design and machine health history.

For information to be useful for monitoring, it must be related to an excitation source on your machine. It's the job of measurement-oriented analysis to relate measurements to excitation sources due to LAV operation. Doing so is important because:

- Measurable responses are indirect indicators of LAV's response to excitation
- Excitation is a function of the LAV's operating environment and operating parameters
- A LAV's response to excitation is a function of machine design, operating conditions (response to excitation changes as a function of it's operating state / environment), and LAV's health

Because it contains a lot of information that relates to various excitation sources, vibration is often the signal of choice for monitoring. With proper acquisition, processing, and analysis, you can relate components of vibration signals to the components of the machine of interest.

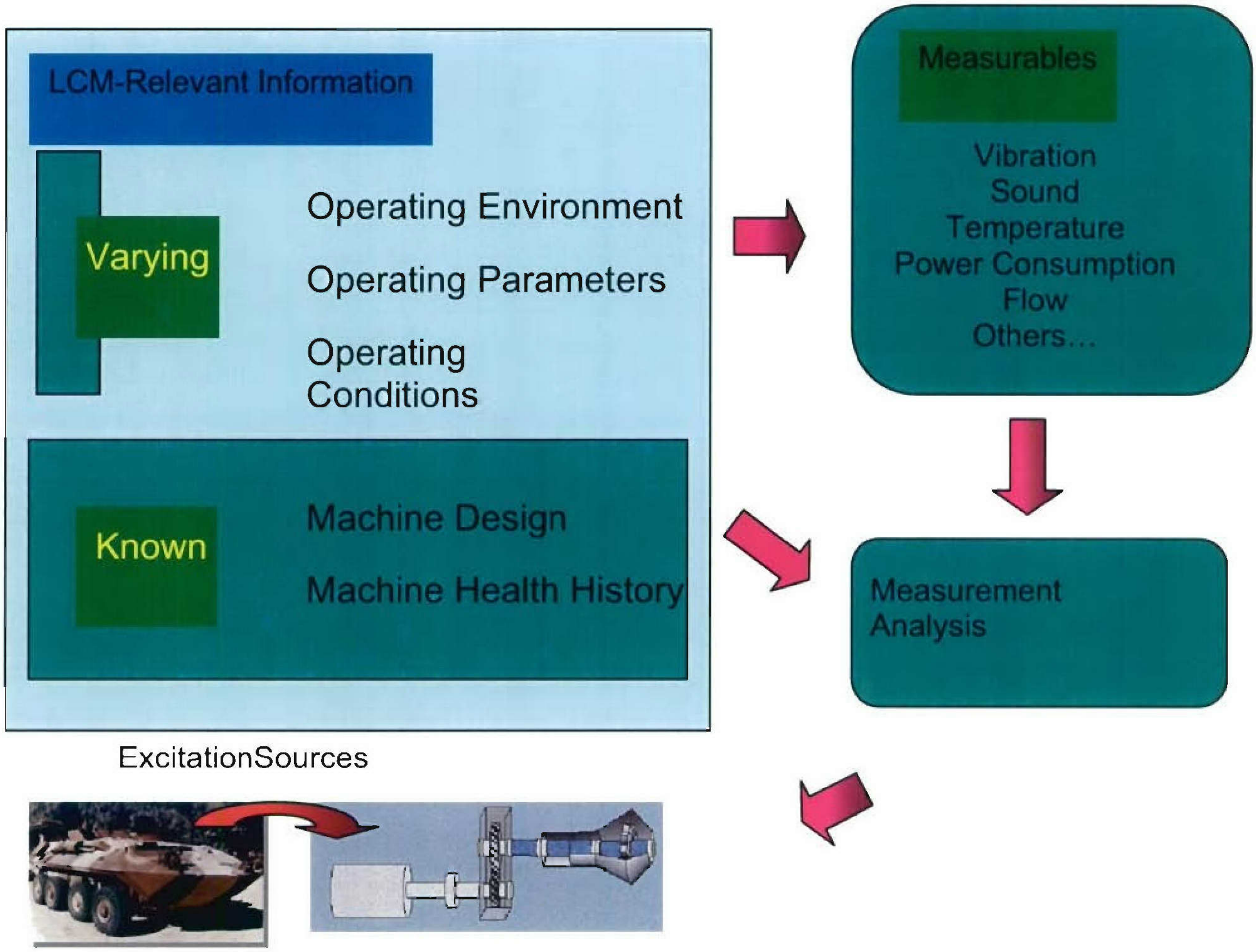


Figure 11.15: LAV Health Monitoring

11.6.6.4 Signal Source Possibilities

- Mechanical Systems with Rotation and Reciprocating Components
- Engines
- Gearboxes
- Tires
- Brakes
- A/C, Engine Cooling
- Transmissions
- Motors / Generators
- Turbines
- Bearings
- Compressors
- Pumps
- Power

11.6.6.5 Vibration Excitation Sources

Let's consider some vibration sources of a generic operating machine. Some vibration sources are due to machine design: slot frequency / EM related, Gears, Coupling, mechanical resonance, and bearings are some examples. Other sources result from potential problems: mechanical looseness, unbalance, and alignment. All of these vibration sources combine into a vibration signal that can be measured [1].

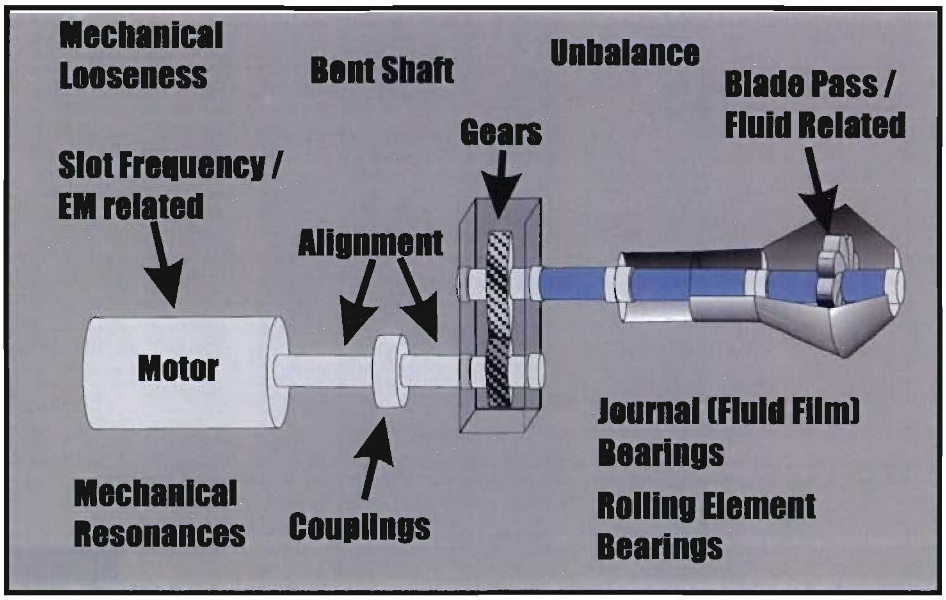


Figure 11.16: Gearbox excitation source

11.6.6.6 Other Possible Signal Sources

There are a number of other available signals to consider when building a machine condition monitoring system for LAV. We've already mentioned measurement of static vibration signals, other common possibilities include temperature, pressure, flow, and level.

- Integrate signals & functionality "As Needed"
  - Temperature
  - Pressure
  - Flow
  - Level
  - Images – Light or Thermal!

11.6.6.7 The Dynamics of Vibration

There are several approaches to measuring vibration. One common way is to measure the overall vibration level. When you do so, you combine the signal sources together into a single aggregate measurement. As a simple example, one might check the static vibration level against some pre-defined limit to determine if manufacturer's specifications are exceeded and maintenance is required.
Although the static measurement approach is appropriate for some applications, others require the more robust viewpoint offered by dynamic measurement. Such a measurement allows you to examine a signal in terms of the components mentioned above. As we'll see, the dynamic vibration signal contains frequency-domain information that can be used to reduce false alarms, assess problem severity, and assist with diagnosis.

- Measurement viewpoints
- Static
  - Level
  - Trending
  - Alarming

- Dynamic
- FFT
- Octave Analysis
- Order Analysis
- Wavelet Analysis

11.6.6.8 LAV Condition Analysis

Processing for machine condition monitoring is a type of translation. Processing transforms the raw signal viewpoint from your transducer into a viewpoint that eases analysis. Analysis for MCM often boils down to comparison: current measurements are compared to or assessed in terms of past measurements.

- Acquire and now...
  - ⇨ Process & Analyze
  - ⇨ Assess Machine Condition
  - ⇨ Assist with Diagnosis
- For Machine Condition Analysis
  - ⇨ Processing = Translation
  - ⇨ Analysis = Comparison

11.6.7 Signal Analysis for Diagnostics

11.6.7.1 Signal Processing = Translation

So, what exactly do we mean by processing?
To answer this question, let's continue with the acceleration signal that shows the signal.

This Figure 11.17 shows how the acceleration amplitude varies as a function of time. Although some repeating components are visible, the pattern appears complex. Such complexity is typical of the sound or vibration that you might measure from any operating machine.
To tame this complexity, you might apply a power spectrum, as shown here.
By depicting signal magnitude as a function of frequency, this type of analysis can often better distinguish source-related signal components. Periodic signal components appear as spikes in this graph [1].

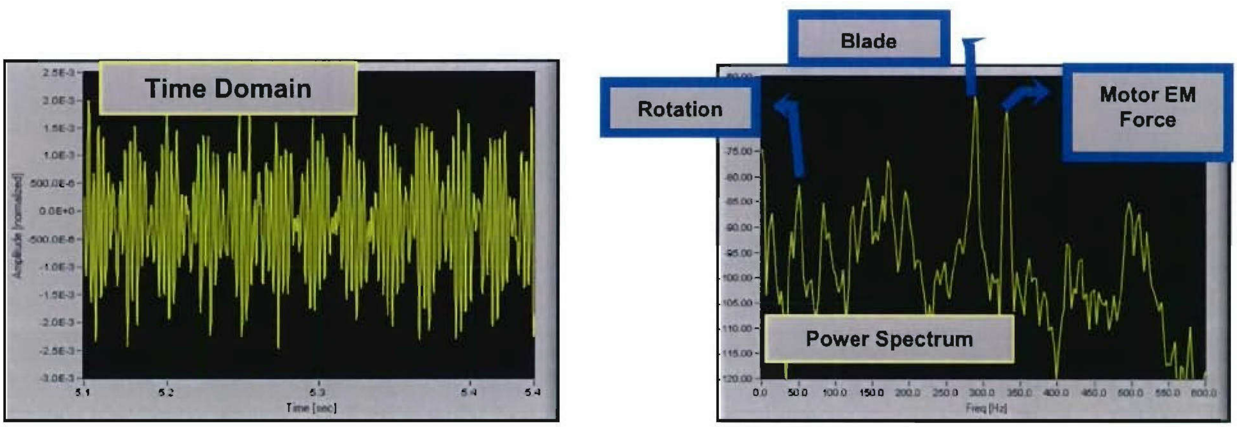


Figure 11.17: Power Spectrum Overcomes Time Domain Signal Complexity

11.6.7.2 Frequency Analysis

Fourier's theorem states that any waveform in the time domain can be represented by the weighted sum of sines and cosines. The same waveform can then be represented in the frequency domain as a pair of amplitude and phase values at each component frequency.

The Fast Fourier Transform (FFT) transforms digital samples from the time domain into the frequency domain. Each frequency component is the result of a dot product of the time signal with the complex exponential at the component frequency.

The DC component is the dot product of x(n) with [cos(0)-jsin(0)], or with 1.0.
The first "bin", or frequency component, is the dot product of x(n) with cos(2pn/N)-jsin(2pn/N). Here, cos(2pn/N) is a single cycle of the cosine wave, and sin(2pn/N) is a single cycle of a sine wave.

In general, the real part of FFT bin k, Re[X(k)], is the dot product of x(n) with k cycles of the cosine wave, and the imaginary part of bin k, Im[X(k)], is the dot product of x(n) with k cycles of the sine wave.

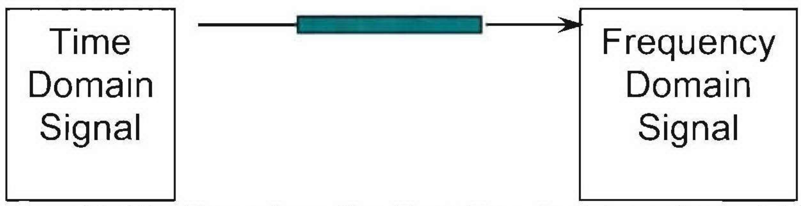


Figure 11.18: Based on the Fast Fourier Transform (FFT)

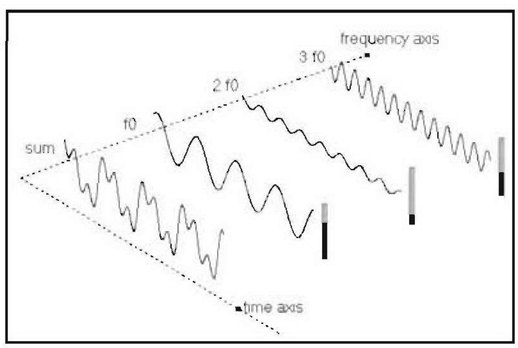


Figure 11.19: Dot product of signal with cosines & sines

11.6.7.3 Order Analysis

When dealing with rotating machinery, you can often hear noise and feel vibration created by the parts, such as bearings, gears, and blades, associated with the rotating components. Vibration of the rotating components creates noise and vibration signals. The machine rotational speed is the source of these signals, and the frequency-domain representations of noise and vibration behave as harmonics of the machine rotational speed. In many industries, the harmonics related to the rotational speed are referred to as orders, and the corresponding harmonics analysis is called order analysis.

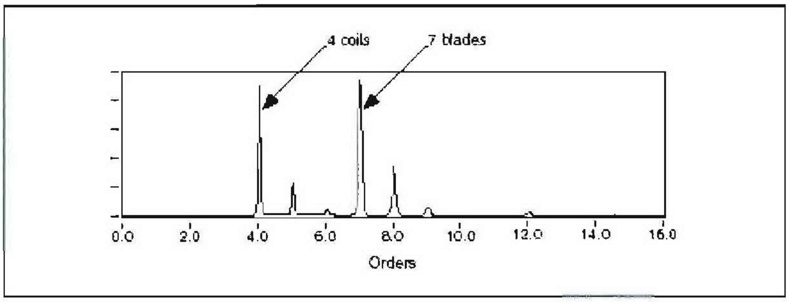
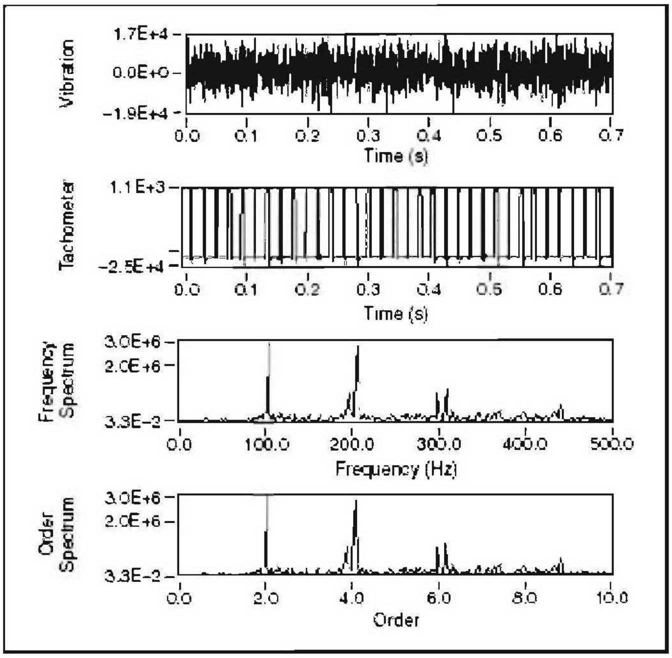


Figure 11.20: Order Spectrum of a PC Fan with Seven Blades and Four Coils

Order analysis is a powerful tool for engineers and scientists to better understand the condition of rotating machinery. Order analysis can be used when a machine runs at a constant speed or when the rotational speed varies [1].



$$Frequency = \frac{RPM}{60} \times Order$$

$$Order = Frequency \times \frac{60}{RPM}$$

Figure 11.21: Order and Frequency Domain Display of Shaft Rotating at 3000RPM

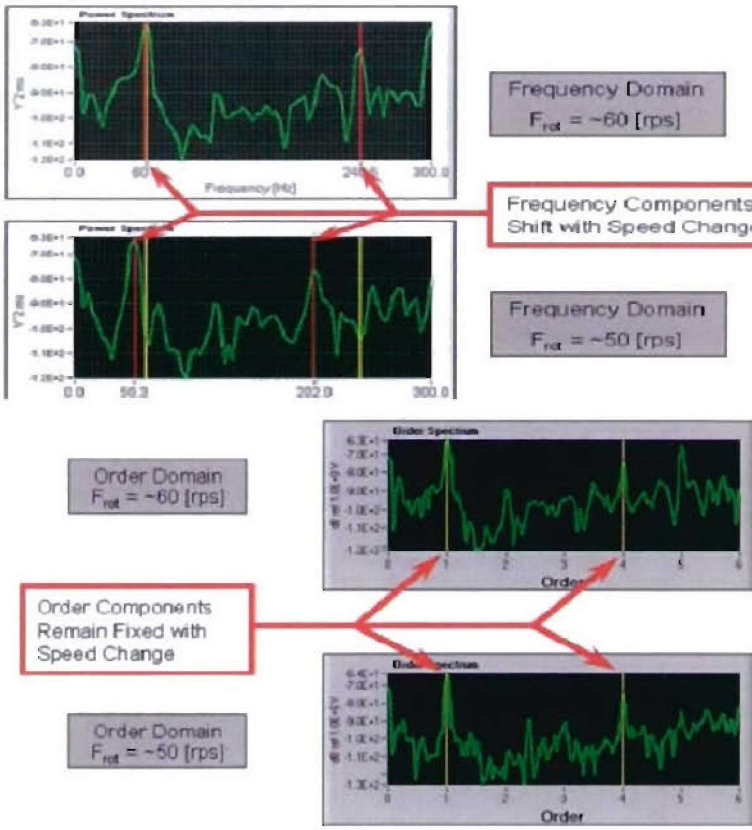


Figure 11.22: Order domain Analysis Fixed Frequencies

11.6.7.4 Fractional Octave Analysis

To get a feel for how comparison is done with the assistance of an analysis tool, consider doing the job with fractional octave analysis. Fractional octave analysis is a type of frequency-domain analysis—it examines the frequency content of a signal. It does so by dividing the spectrum up into constant-bandwidth octave bands, which are commonly presented on a logarithmic frequency scale as a bar graph.

- Examines signals in the frequency domain
- Divides frequency domain into manageable octave bands
- Log frequency scale

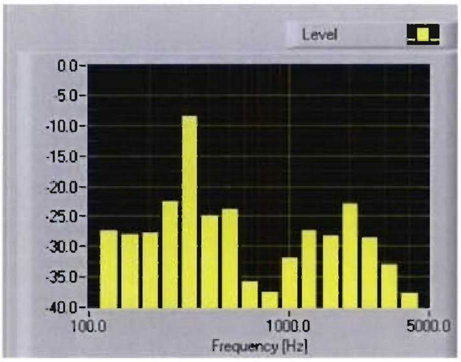


Figure 11.23: Factional Octave Analysis

Fractional octave analysis proves useful for comparison of the frequency content of a signal for several reasons:

- "Smart Data Reduction" – while standard FFT-based power spectrum might return 256, 512, etc, measurements, as frequency bins, Octave analysis typically returns 20 or so measurements as octave bands. Fewer measurements means that the job of comparison is simplified and that the data logging / trending portion of an MCM won't need to churn through as much data.
- Based on IEC / ANSI standards – Standards have defined how to perform fractional octave analysis, so if you work with a standards-compliant fractional octave tool (such as what's included with the Sound & Vibration Toolset for LabVIEW), you will get consistent results that you might compare with other measurements taken under the auspices of the same standard [1].

11.6.7.5 Wavelet Analysis

Wavelets offer a much better signal representation leading to a good spatio-temporal decomposition. We will discuss Wavelet analysis in a later section.

11.6.8 Conclusion What we've demonstrated thus far involved acquisition, signal processing, and analysis that you can apply to LAV condition monitoring. These elements might serve as a portion of a front-end for a comprehensive LAV condition monitoring system. By sharing data over a LAN, the Internet, or even wireless, you could, for instance, monitor multiple machines, generate HTML status reports, and remotely check in on plant status from a home PC.

• After Acquisition, Signal Processing, and Analysis, the tasks are:

- Report Generation (HTML)
- Data Sharing (between programs, across the network or Wireless)
- Remote Monitoring (Across Inter-, Intra-net, Wireless)

In the next report, we will detail them with specific reference to LAV CBM.

11.6.9 References

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11.7 Appendix: 5 – Condition Based Maintenance in Army

11.7.1 Condition Based Maintenance

11.7.1.1 Definition
11.7.1.2 Major CBM Programs in the Services
11.7.1.3 CBM System Block Diagram
11.7.1.4 Commercial CBM infrastructure

11.7.2 CBM in Army

11.7.2.1 Concept
11.7.2.2 Block Diagram
11.7.2.3 Case Study: M1 Abrams main battle tank (MBT)

11.7.3 CBM in Army Helicopter equipments

11.7.3.1 Concept
11.7.3.2 Block Diagram

11.7.4 Summary

11.7.5 References

11.7.1 Condition Based Maintenance [1], [2]

11.7.1.1 Definition

CBM is initiated by sensing equipment condition. CBM is defined as a set of actions taken as a consequence of knowing the current operating status of the equipment. Determining current equipment operating status is accomplished in three basic ways:

- By using sensors and computers that are embedded into the operating equipment and monitored on-the-fly,
- By applying portable sensing equipment that marries up to an interface or wiring harness to "read" embedded sensors, or to apply the sensor itself, such as a stand-alone wear measurement,
- By using manual gauges or instruments, such as a tire-wear gauge

We should be clear as to the intent of CBM, as well as its capability. The intent of CBM is to perform maintenance only when there is objective evidence of need. The technical capability of CBM is to identify current equipment conditions. What we do with these condition indicators is more than a matter of being able to schedule maintenance or forecast failure. Done right, with objective evidence of need in hand, we forecast or schedule maintenance tasks. However, steps must be taken beforehand—before CBM is applied to a given task—to ensure it is a cost-effective task in the first place.

11.7.1.2 Major CBM Programs in the Services

We can consider the following four programs, based on their size and scope:

- Joint Strike Fighter Prognostic Health Management (JSF-PHM)
- Navy Integrated Condition Assessment System (ICAS)
- Army Diagnostic Improvement Program (ADIP)
- Integrated Mechanical Diagnostics, Health Usage & Monitoring System (IMD-HUMS), a helicopter CBM program

The JSF is a new design weapon system, just completing concept development. JSF PHM represents what can be done with current technology when weapon system design and CBM design go hand-in-hand. The other programs address improved CBM capabilities for legacy weapon system fleets.
This report will examine the three programs, ADIP and IMD-HUMS by describing the concept and block-diagram. In other words, this report describes the operational concept in simplified terms to facilitate comparison of basic program

concepts, and we also show a similar block diagram for each program which identifies the major components and how the programs differ at this level.

11.7.1.3 CBM System Block Diagram

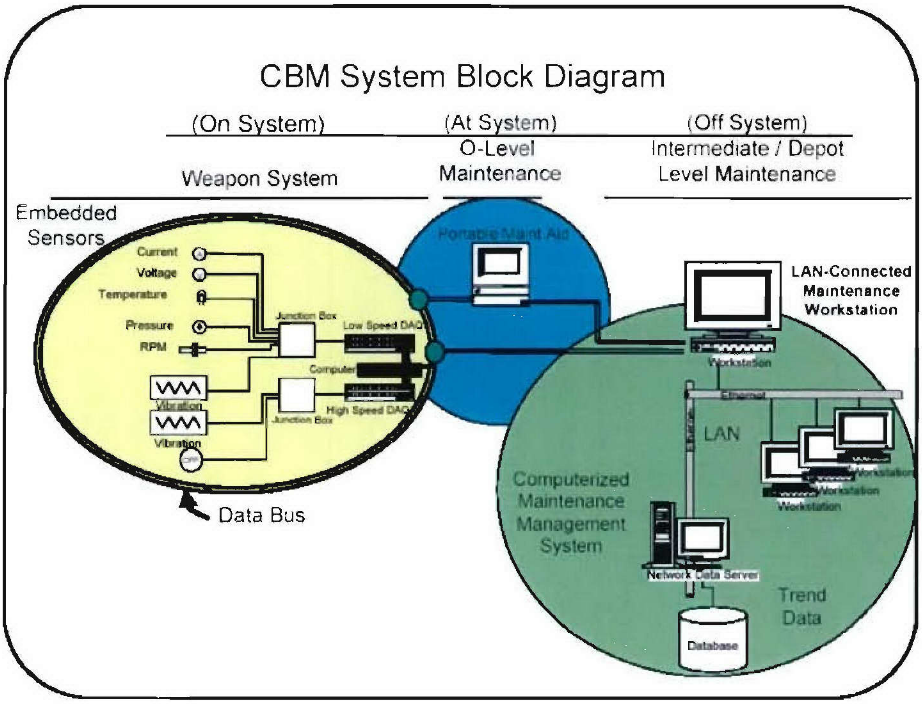

Figure 11.24: CBM System Block Diagram

Overview

For the CBM system block diagram, we can introduce the terms of on-system, at-system and off-system (system in this latter instance referring to weapon system), instead of using the on-board/off-board terms. This stems from the need to introduce the use of portable equipment that performs condition monitoring and runs the IETM.

- On-system – the embedded (on-board) sensors and computers from which condition-monitoring data is collected. This also includes the data bus or wiring harness and connectors that carry the signals from the sensors.
- At-system – the portable maintenance aid and/or portable sensoring equipment used periodically to check equipment health.
- Off-system – this is synonymous with off-board, except concerning Navy ships. Navy ships keep the workstations on-ship; so; from a NAVSEA perspective, everything is on-board. We will call this shipboard when discussing Navy surface ship CBM.

Open Systems Architecture

A block diagram can help visualize the key interfaces and standards that are fundamental to open systems architecture design. The standards committees of the Institute of Electronic and Electrical Engineers (IEEE) and the Society of Automotive Engineers (SAE) play key roles for defining interface and component standards (as do others). We highlight key areas where these standards underpin an open architecture design.

Data Bus

The data bus specification is a key design element to achieving open systems architecture.

- Physically, a data bus replaces part of a weapon system wiring harness and significantly reduces harness wiring. It may be fiber-optic or wire.
- Functionally, the data bus is a local area network (LAN) for the vehicle and can have redundant capability for fault-recovery purposes, as it does in most modern fighter aircraft and ground fighting vehicles.
- From an interface standpoint, a data bus is an interface portal providing access from external devices to embedded sensors and computers.

There are only a handful of data bus definitions. If the weapon system employs an industry standard data bus, such as the J1708 or J1939 data buses specified by SAE, or the Mil-Std-1553 data bus, then the hardware interface to the embedded computer is a well-described entity which facilitates third-party commercial off-the-shelf (COTS) component suppliers. The data bus does not have to comply with an industry standard to enable open systems, as long as the definition of signals is openly available, such as the NAVSEA Integrated Carrier Advanced Net-work (ICAN) program, which is now specified for a fiber-optic backbone in the new generation of aircraft carriers.

Messages on the Bus

Open Architecture design facilitates by specifying the message traffic on the data bus in some standard fashion. SAE has learned from the earlier Mil-Std-1553 data bus experience in this regard. SAE has defined companion message proto-cols for the hardware bus. Mil-Std-1553 does not do this, which forces a retrofit systems integrator or CBM developer to learn the message protocol for every sub-system, each of which typically differs significantly from the other.

Embedded Sensors

Fundamental to all CBM systems is a suite of embedded sensors of various types. The more sophisticated the system, the more diverse the sensor technologies and the greater the density of sensors employed. The IEEE now specifies a sensor object model that defines sensor features. The SAE does this also. Older weapon systems accessed sensors directly via a wiring harness routed to a common connector; newer systems use a data bus. Some ground systems in the Army have both, which may complicate access to data. Some older aviation systems are also only partially integrated, again limiting data access.

Embedded Computers

All new weapon systems employ on-board computers, in many cases, in conjunction with data acquisition channels and data storage capacity. Embedded computer design generally follows industry standards, depending on the form factor, processing power, storage requirements, and interface needs of the system. An open system architecture design will specify a particular computer architecture and also provide input/output (I/O) expansion capability using a known interface standard.

Portable Maintenance Aid (PMA)

The PMA may or may not be part of the CBM data-monitoring and data-collection effort. In more sophisticated CBM systems, the PMA runs an IETM that uses the PMA to connect to the embedded data bus and extract sensor information to aid the troubleshooting process. The PMA links to the off-board (or analytic) part of the CBM system to download troubleshooting and/or "health check" information to the database and trend analysis system.

The computer architecture of the PMA is most often based on a popular portable PC architecture, such as Intel or Apple, and, more recently, the Palm handheld devices. This practice significantly lowers acquisition costs, though it places a burden on the systems integrator to address "ruggedization" features.

Off-board Computerized Maintenance Management Systems (CMMS)

The off-board part of the CBM system is typically a networked workstation environment using the Ethernet (IEEE 802.1) standard. One computer generally acts as the interface to the embedded/PMA components, while the database resides on another computer somewhere on the network and operates in a shared environment.

On the industrial side of CBM and CMMS, suppliers typically address these standards in their product offerings.

Turn-key CMMS Solutions

The commercial CBM industry provides a range of system solutions, from individual software packages to complete turnkey systems. The Navy's ICAS system is an example of a CBM system that started as a turnkey package of sensors and an off-board CMMS system and gradually added capabilities from a base plat-form.

Database

The database is a key area for open standards; it is typically addressed when selecting the supplier of the database management system. The rise of Internet functionality and web-enabled commerce supply chains is creating a new generation of database concepts that may soon replace the traditional database suppliers. These are all based on open Internet standards, and will create a new dimension for C4I systems architecture.

11.7.1.4 Commercial CBM infrastructure

A CBM infrastructure has been built over time in the commercial sector that helps guide its effective employment and promotes sharing of information across industries. This infrastructure represents a set of resources for military programs to build upon in their own CBM programs.

Being able to capitalize on the richness of the commercial CBM sector infrastructure is one of the principal reasons to design weapon system and associated CBM programs on an open architecture basis.

The commercial machinery sector has an open-systems forum comprised of a consortium of companies that use or supply CBM technology—Machinery Information Management Open Systems Alliance (MIMOSA). MIMOSA is comprised of over 50 companies that participate in an open-exchange of ideas and practices. Substantial benefits are available to the Services and their suppliers by joining MIMOSA. This could promote a beneficial exchange among all parties, ensuring that MIMOSA open standards reflect Service requirements for CBM and other predictive maintenance applications. For example, it was noted at a recent CBM symposium that requirements for exchanging shipboard maintenance in-formation could be included in MIMOSA's open conventions and protocols.
A number of universities sponsor centers focused on reliability, machinery diagnostics or CBM. Generally, these centers are integral to the universities' engineering departments.

In the commercial sector, there are professional societies that focus on condition-monitoring and professional journals and periodicals dedicated to examining technology, applications and economic considerations in CBM and other maintenance concepts. A wide range of articles provides relevant information pertaining to CBM technology and business case discussions.

11.7.2 CBM in Army [1], [2]

11.7.2.1 Concept

ADIP is aimed at improving the diagnostics and prognostics of all Army weapon systems and equipment by the application of common technologies across multiple systems. ADIP addresses all Army commodities and systems. In fact, it ad-dresses more types of equipment than any other Service program and is the broadest in scope of DoD's legacy equipment maintenance improvement pro-grams.
ADIP has three time-phased "thrusts" grouped according to the time frame required for implementation. The Program Manager for Test, Measurement, and Diagnostic Equipment (PM-TMDE) oversees the program through a series of integrated product teams whose membership is drawn from equipment program manager (PM) offices and Army staff agencies. The three thrusts are:

Short-term - immediate technology insertion programs to improve diagnostics

Mid-term - to develop anticipatory maintenance capability in ground vehicles and helicopters

Long-term – is to develop an embedded diagnostics proof-of-concept for a common architecture and approach (similiar to the JSF PHM embedded architecture design goals).

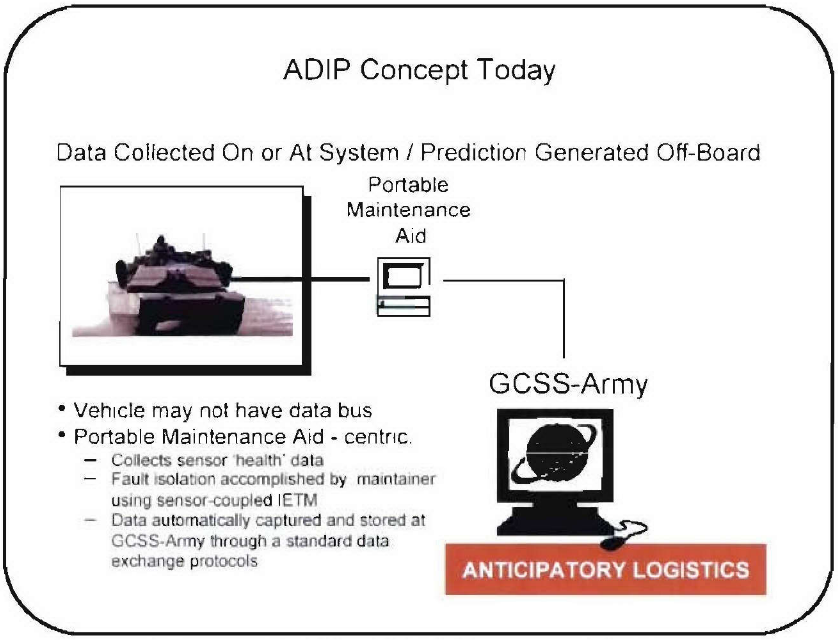

Figure 11.25: ADIP Concept Today

The ADIP CBM concept today is to access on-board data using the PMA as the primary data collection and communication tool. The PMA runs sensor health checks, and the sensor-coupled IETM automatically collects the data and transmits it to GCSS-Army.

PM-TMDE and PM-GCSS-Army have jointly developed software interfaces to GCSS-Army that apply to IETM data capture and to vehicle health data.

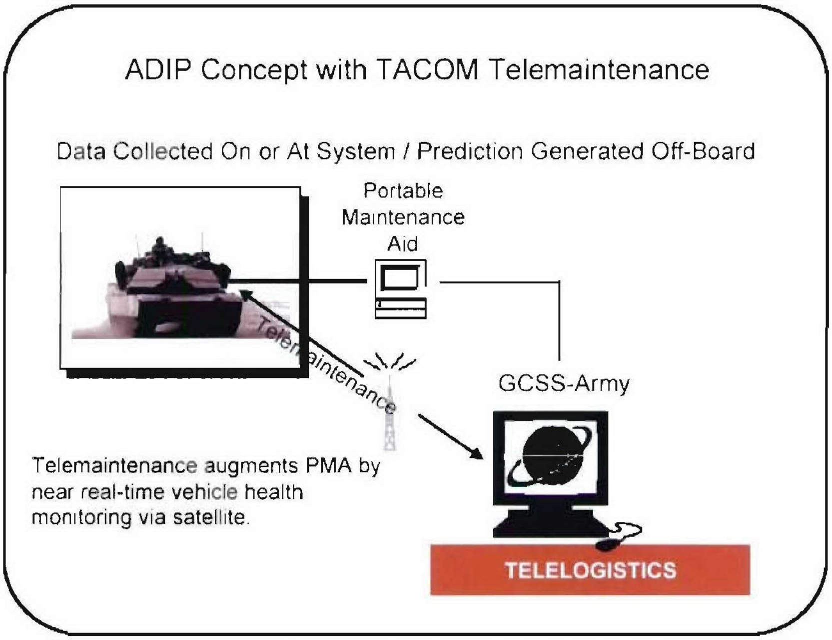

Figure 11.26: TACOM Tele-maintenance

Tele-maintenance, which means collecting of on-board vehicle health data and transmitting it via long-range communication media to a maintenance support center for analysis, is under development by the Tank-Automotive and Armaments Command (TACOM) in Detroit. LIA is funding and supporting TACOM in this effort. Like JSF's autonomic logistics, Tele-maintenance supports Tele-logistics by linking the maintenance center and/or the individual vehicle to the logistics system through the maintenance center. At TACOM, the Electronic Maintenance System (EMS) handles the sensor-coupled IETM and the PMA collection of vehicle sensor health data. EMS integrates the resulting information into the logistics system and enables real-time tracking of vehicles and weapon systems and their maintenance status.

11.7.2.2 Block Diagram

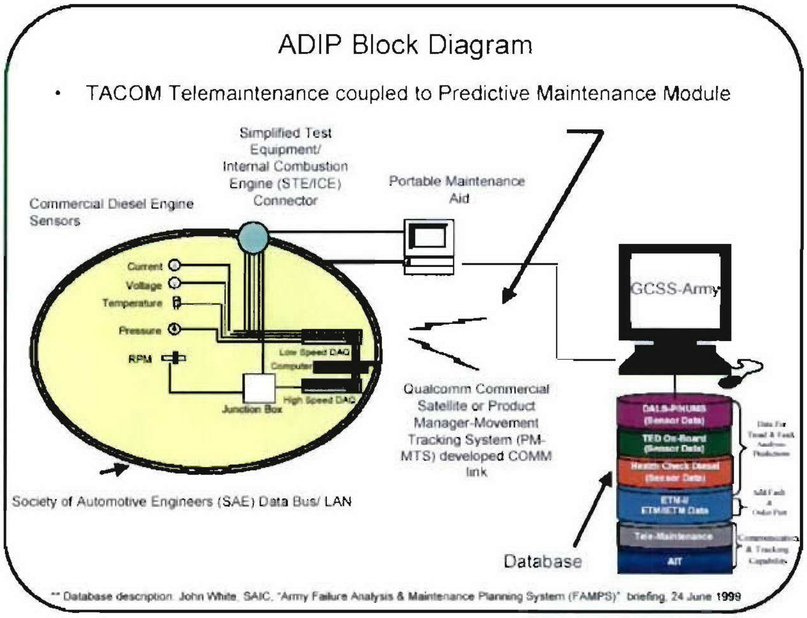

Figure 11.27: ADIP Block Diagram

The on-board hardware components of ADIP are COTS, delivered as a package by the engine, transmission and other vehicle subsystem OEMs, and integrated into the vehicle by the vehicle OEM.

Embedded Sensors

Sensors in Army vehicles come in two distinct forms, those on mechanically controlled engines and those on electronically controlled engines. The older mechanical engines are being phased out of Army and U.S. Marine Corps (USMC) inventory as part of vehicle remanufacturing programs, such as the USMC Medium Tactical Vehicle Replacement program, or new vehicle development, such as the Army Family of Medium Tactical Vehicle program. Vibration sensors are not presently in the Army suite of sensors used for CBM purposes as commercial diesel engine OEMs have not provided them.

PMA Functionality for CBM

The PMA reads the vehicle sensors either directly via a common multiple-pin connector, or by connecting to the data bus and capturing the data from sensors that have been processed by the on-board engine control unit. The PMA collects the sensor data through a stand-alone process known as a health check, or it selectively interrogates only those sensors appropriate to a troubleshooting session for a known symptom, using the sensor-coupled IETM.

GCSS-Army Interface and Interaction

One of PM-TMDE's major CBM initiatives has been the development of the Predictive Maintenance Module (PMM), previously known as the Failure Analysis

and Maintenance Planning System (FAMPS). This is essentially a database capability for collecting, storing, analyzing and acting on equipment condition trends identified in the data. There is a high degree of collaboration with PM-GCSS-Army and its Army Combined Arms Support Command (CASCOM) parent. This sets the ADIP program apart from other CBM system developments, given the extent and nature of the interfaces developed and the modifications made to the GCSS-Army information system to support predictive maintenance functionality.

Database

The Army database[6] that stores and analyzes vehicle health data contains many separate compartments of vehicle health information. As a result, the database is structured to facilitate individual weapon system capabilities in health data collection. For example, separate data definitions are provided for TED (Turbine Engine Diagnostics), a program apart from ADIP, but for which ADIP makes provisions for incorporation into the GCSS-Army PMM.

The power of the predictive nature of the system is extended by correlation with geographic and weather data, which is collected from NOAA, the National Oceanic and Atmospheric Agency, and stored in the GCSS-Army data base. This data can then be used to determine, for example, environmental impacts on equipment degradation and maintenance requirements.

11.7.2.3 Case Study: M1 Abrams main battle tank (MBT) [3]

The U.S. Army's current maintenance practices for the M1 Abrams main battle tank (MBT) mainly employ manual diagnostic procedures. Efforts are continually underway to make improvements in materials, electronics/control systems, and automated processes to increase the reliability and performance of the equipment. Nevertheless, current manual processes as well as automated enhancements still generally verify only whether the operational states are within or out of tolerance. For this system, and more particularly for future high-value/high cost vehicles and platforms, there is a need to achieve real-time engine condition monitoring and prediction of near-term vehicle health and readiness. This enhanced technology promises to improve logistics and maintenance processes by enabling reductions in maintenance staff hours, improvements in diagnostic performance, increasing readiness, and providing the information required to optimize maintenance scheduling based on need. This paper describes a current research and development project aimed at fielding a proof-of-concept operational prototype engine health monitoring and prognostic system.

Figure 11.28: M1 Abrams MBT

Under an Interagency Agreement with the U.S. Army Logistics Integration Agency, Pacific Northwest National Laboratory (PNNL) is developing a prototype diagnostic/prognostic system for the MBT's AGT1500 turbine engine that uses artificial neural networks to diagnose and predict faults. The operational prototype system is called TEDANN, for Turbine Engine Diagnostics using Artificial Neural Networks (Greitzer et al. 1997; Illi et al. 1994; Kangas et al.1994). The main tasks of the TEDANN project are to develop prototype data acquisition hardware, to design and implement health monitoring software, and demonstrate the proof-of concept system.

TEDANN receives input from 48 sensors mounted on the AGT1500 engine. Of these sensors, 32 are factory installed for engine control and basic diagnostics performed by the engine control unit. The other sixteen sensors—retrofitted to the engine using a wiring harness—include seven pressure sensors, six temperature sensors, two chip detectors, a vibration sensor and an inclinometer. Advanced microsensor technology has been exploited in this and related projects (Wilson et al. 1999). The thermodynamic (temperature, pressure, RPM, etc.) sensors are located at strategic points along the gas flow in the engine to provide more detailed thermodynamic picture of the engine's state. The TEDANN prototype is contained in an enclosure about one foot square and 3 inches high. The sensor signals are conditioned using two printed circuit boards, multiplexed to a data acquisition card, and then analyzed by a Pentium microprocessor.
If fully deployed in the field, the TEDANN system would be integrated with other electronic systems onboard the tank.

TEDANN is being developed using model-based diagnostics and artificial neural networks. This technology allows the diagnostic/prognostic system to model normal engine performance, learn to recognize deviations from normal behavior, and classify these deviations as conditions requiring maintenance attention.

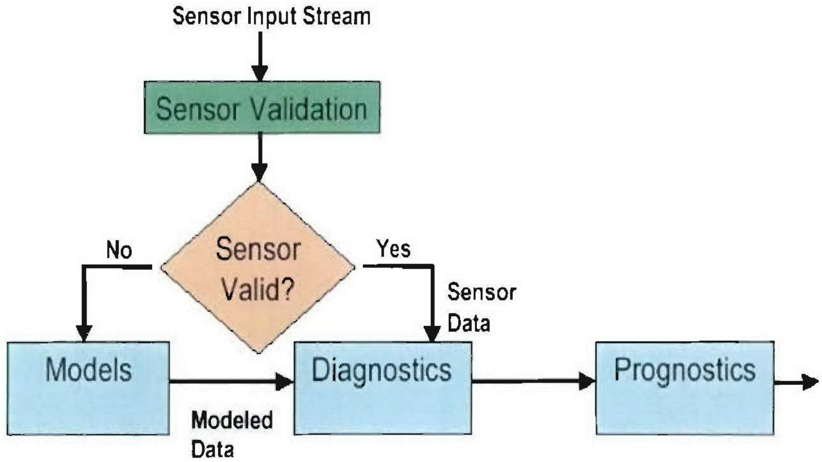

Figure 11.29 Diagnosis and Prognosis on TEDANN

The sensor values are first analyzed to determine if they are valid, i.e., within expected operating ranges. If any sensor is determined to be faulty, a modeled value is substituted for the observed value. Artificial neural networks and a set of rules are used to model the sensor values and support sensor validation. Following the sensor validation, the sensor data are processed by diagnostic modules. Diagnostic processing includes rule-based and ANN-based analyses. Rule-based analyses check to see if one or a few sensor values exceed thresholds or fail to follow thermodynamic relationships. ANN-based analyses provide diagnoses of complex faults requiring parallel analysis of a large number of sensors. An unsupervised, self-organizing ANN classifies engine operations into states, such as low-idle, tactical idle, full power, etc. Other supervised, feed-forward ANNs perform engine modeling and pattern recognition to diagnose specific faults and conditions. Such model-based diagnoses are output as parameters that are analyzed in TEDANN's prognostic module.

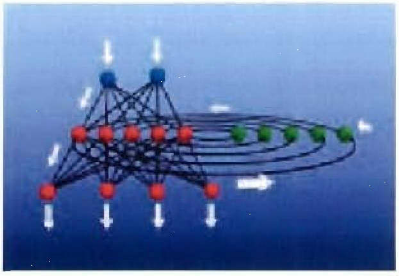

Figure 11.30: ANN model in engine

11.7.3 CBM in Army Helicopter equipments [1], [2]

11.7.3.1 Concept

The IMD-HUMS is a Commercial Operations and Support Savings Initiative (COSSI) program. This is an Office of the Secretary of Defense (OSD)-sponsored program to accelerate fielding of dual-use technologies (i.e., commercial) that satisfy military needs and have high potential to reduce operations and support costs. IMD-HUMS stemmed from helicopter safety problems in the Presidential helicopter fleet; a 1993 White House requirement memo initiated the program.

The IMD-HUMS program integrates and tests a commercial/military “dual use” mechanical diagnostic system from BFGoodrich on the H-53 and H-60 Sikorsky helicopters. This program is coordinating with the Joint Advanced Health Usage & Monitoring System (JAHUMS), a separate CBM technology development project, in order to use the JAHUMS project for risk reduction in testing key technologies.

There are a number of other HUMS programs, domestic and international, that represent a source of lessons learned and potential collaboration. Internationally, both the United Kingdom Ministry of Defence and the Canadian Defence Forces have developed and fielded HUMS for helicopters. The U.S. Army PM-TMDE is sponsoring a HUMS program for the Army independent of both IMD-HUMS and JAHUMS, working with the South Carolina National Guard. These various efforts appear to be legitimate sources for effective collaboration.

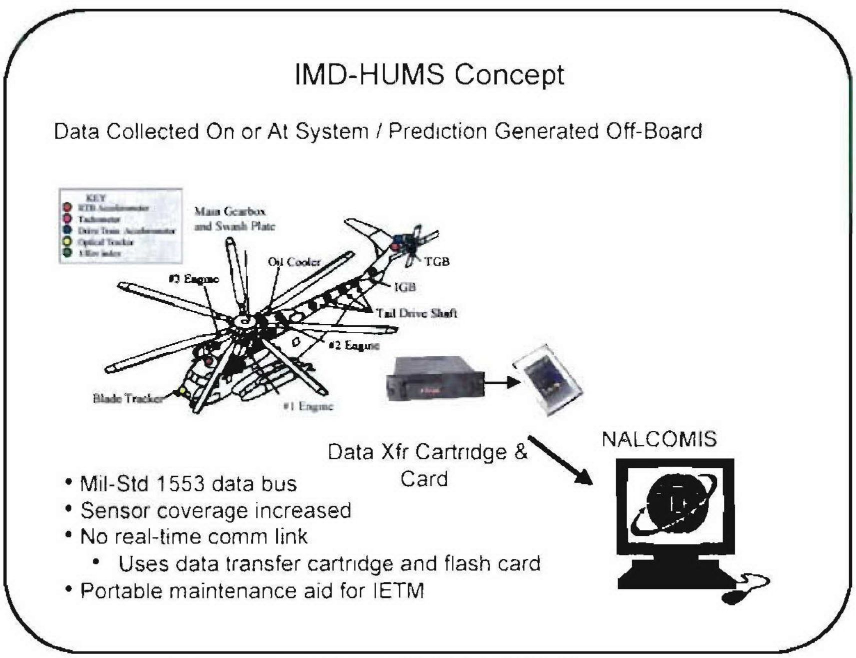

Figure 11.31: IMD-HUMS Concept

IMD-HUMS provide for full-time in-flight monitoring and collection of engine and mechanical drive systems health information. This monitoring process includes flight regime information necessary to make prognostic forecasts of remaining equipment life, and structural and operational usage.

When the helicopter is on the ground, the data transfer cartridge containing in-flight condition data is retrieved and sent to the Naval Aviation Logistics Command Management Information System (NALCOMIS) Optimized Organizational Maintenance Activity (OMA), where it is analyzed for early identification and correction of degraded components in the engine, drive train, and rotor systems of the helicopter.

IMD-HUMS provides for cockpit display, alerting aircrew of aircraft health data considered to have an impact on immediate flight safety. A portable computer functions as a portable maintenance aid running a traditional Class 3-4 IETM (i.e., not sensor-linked).

11.7.3.2 Block Diagram

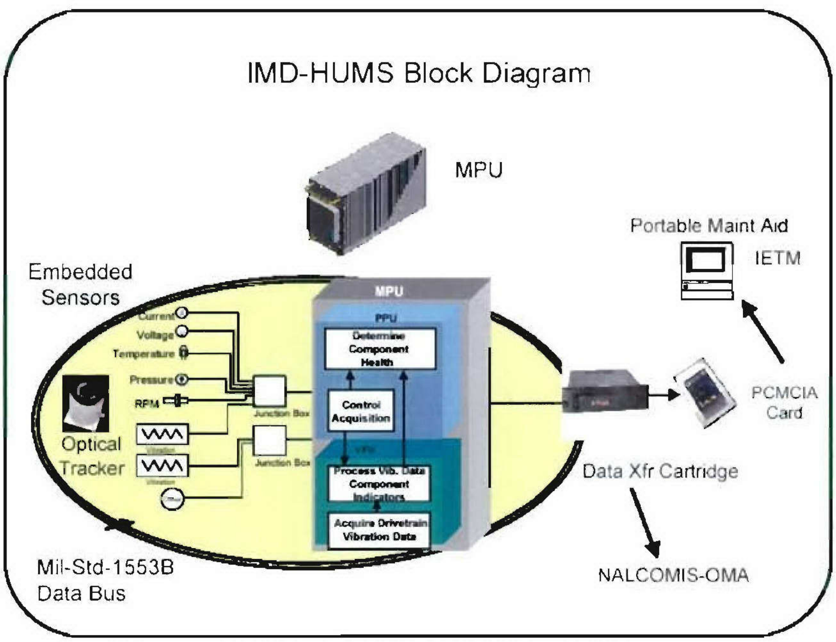

Figure 11.32: IMD-HUMS Block Diagram

Major on-board hardware components include: (1) the main processor unit (MPU), whose principal functions are shown in the chart, (2) an optical tracker unit, used for rotor track and balance evaluation, (3) data concentrators, and (4) an array of various sensors. Vibration and temperature sensor data are collected to aid flight regime analysis.

An IETM resides on a portable maintenance aid that reads a PCMCIA card loaded with selected in-flight condition data used to assist troubleshooting and repair.

11.7.4 Summary

JSF PHM is the most comprehensive technology development program reviewed for this report. It is the DoD leader in technical capability and in the articulation of program goals measured by appropriate metrics. And it has the longest time horizon (>40 years). Additionally, JSF PHM is built upon an open-systems architecture with the integration of COTS technology where feasible. It has pioneered the concept of autonomic logistics.

ADIP addresses the most diverse fleets of weapon systems and the greatest numbers and kinds of equipment. ADIP has pioneered the technology-enhanced, sensor-coupled IETM. It has a vision of achieving embedded PHM capability similar to the JSF program, but present capability uses a PMA-centric approach to capture and transmit equipment health data to a processing center that can mine the data for predictive information. ADIP has worked extensively with GCSS-Army to develop and augment GCSS-Army with a predictive maintenance module capacity and has specified the software interfaces and data elements needed to accomplish this. The goals of ADIP are the most specific shown, but still to be developed are program metrics to monitor progress in attaining those goals.
ICAS addresses the most substantial technical challenges reviewed in this report as measured by the range and kinds of older non-digital ship propulsion and HM&E systems it attempts to address. It limits CBM goals to cost reduction in the form of reducing man-hours spent recording data in the ship logbook, and does not address logistics support linkage or integration. Technically, ICAS is an adaptation of the trademarked COTS CBM system from IDAX, Incorporated, and is self-contained on each ship that implements ICAS.

IMD-HUMS is more a platform-specific project than a Service CBM program, but it does address multiple helicopter fleets. It has designed a sophisticated methodology for in-flight condition-monitoring that approaches prognostic capability. It does not attempt real-time condition-reporting or downlinking data while in-flight, but it does provide significant capability for early detection of impending problems in many complex mechanical systems associated with the helicopter drive train.

11.7.5 References

[1] Steven W. Butcher. "*Assessment of Condition-Based Maintenance in the Department of Defense*". Logistics Management Institute, August 2000.

[2] Frank L. Greitzer and et al. "*Gas Turbine Engine Health Monitoring and Prognostics*". The International Society of Logistics 1999 Symposium, Las Vegas, Nevada, August 30 1999.

[3] Lars J. Kangas and et al. "*Automated Health Monitoring of the M1A1/A2 Battle Tank*". USAF Inaugural Engine Condition Monitoring (ECM) Workshop, October 1997, San Diego, CA.

11.8 Appendix: 6 – Commercial Practices of Maintenance in Aviation

11.8.1 Introduction

Aviation maintenance technology focuses on aircraft airframe and power-plant maintenance. This section focuses on three aspects: (1) Comparing the aviation operation, maintenance environment and management between Boeing and Airbus. (2) Understanding the MSG-3, which is the latest maintenance program in Boeing fleet. (3) Defining requirements for monitoring the health of the airplane engine. The material is extracted from some of the references cited.

11.8.2 Airbus Vs. Boeing: Modern Aircraft Maintenance

In the Airbus designing process, maintainability is already under consideration. By applying Fly-by-wire technology on the A330/A340 family, and a long-time Airbus design feature, has contributed to make maintenance simpler. Here are some illustrations of Airbus maintenance features:

(1) One aspect of maintenance that is improving is engine monitoring. The high cost of engine removals has sparked a trend toward longer time on wing. On the A340, for example, parameters are easier to analyze, and this makes it easier to determine the right time to remove the engine, avoiding unnecessary early removals.

(2) A significant step forward for Airbus maintenance is the centralized maintenance computer. Formerly, built-in test equipment was scattered and you had to work with several computers. Aircraft CMC (central maintenance computer) gives comprehensive information (including history of parameters) in plain English.

(3) Datalink, a technology that provides digital information flow between ground services and flight decks, via the satellite-based ACARS (Aircraft Communication & Address Reporting System) allows real-time monitoring of in-flight aircraft. Data is received in airport and forwarded to other bases if necessary. Airbus can anticipate what kind of maintenance equipment and spare parts are needed at the next stopover. Experts can find a solution that can be performed during flight.

(4) For future demand, an ever-more integrated avionics suite will avoid the coexistence of conflicting software.

Besides Airbus, Boeing also has some unique components and features in its maintenance system:

(1) MyBoeingFleet.com is a website that customers can access as a single point of contact for obtaining virtually all the information they need to maintain and operate their Boeing fleets. Whether ordering spare parts,

retrieving technical drawings and service bulletins, collaborating with other carriers on technical issues, sharing fleet data or even filing warranty claims.

(2) To further improve logistics support, Boeing's innovative GAIN (Global Airline Inventory Network) program manages the supply chain for expendable airframe parts and saves airlines inventory-holding costs.

(3) Airplane Health Management, for example, is an integrated family of information products and services that will collect monitor and analyze airplane data on in-service airplanes, allowing for faster repairs and, in many cases, the ability to predict faults and prevent equipment failures before they occur.

(4) Alteon provides comprehensive learning programs for maintenance technicians, supported by computer-based training aids, simulators, and on-site sessions at customer locations.

(5) Boeing designs ground support equipment, apply human-factors research to reduce maintenance errors, conduct a variety of maintenance-related consulting services and studies, and offer periodic maintenance seminars to help airlines improve proficiency.

(6) Boeing has two subsidiaries. Continental DataGraphics provides customized documentation to airlines, including parts catalogs and digitized information. AeroInfo Systems develops advanced software to manage maintenance activities.

(7) MSG-3 standard (Maintenance Steering Group, 3rd edition) has been successively developed by the industry to create more efficient maintenance programs, by analyzing failure modes and their level of criticality.

11.8.3 MSG-3 (Maintenance Steering Group, 3rd edition)

Airline and manufacturers experience in developing scheduled maintenance for new aircraft has shown that more efficient programs can be developed through the use of logical decision processes. Historically, the initial scheduled maintenance tasks and intervals have been specified in Maintenance Review Board (MRB) Reports. MSG-3 is intended to facilitate the development of initial scheduled maintenance. The remaining maintenance, that is, non-scheduled or non-routine maintenance, consists of maintenance actions to correct discrepancies noted during scheduled maintenance tasks, other non-scheduled maintenance, normal operation, or data analysis. This report addresses the development of scheduled maintenance using the MSG-3 analysis procedure.

11.8.3.1 Development of Scheduled Maintenance

The objectives of efficient aircraft scheduled maintenance

- To ensure realization of the inherent safety and reliability levels of the aircraft.
- To restore safety and reliability to their inherent levels when deterioration has occurred.
- To obtain the information necessary for design improvement of those items whose inherent reliability proves inadequate.
- To accomplish these goals at a minimum total cost, including maintenance costs and the costs of resulting failures.

The content of the scheduled maintenance itself consists of two groups of tasks
A group of scheduled tasks to be accomplished at specified intervals. The objective of these tasks is to prevent deterioration of the inherent safety and reliability levels of the aircraft. The tasks in scheduled maintenance may include:

- Lubrication/Servicing (LU/SV)
- Operational/Visual Check (OP/VC)
- Inspection/Functional Check (IN/FC)
- Restoration (RS)
- Discard (DS)
- A group of non-scheduled tasks which result from
- The scheduled tasks accomplished at specified intervals
- Reports of malfunctions (usually originated by the operating crew)
- Data analysis

The objective of these non-scheduled tasks is to restore the aircraft to an acceptable condition. As the essence of automatic logistics, an efficient program is one, which schedules only those tasks necessary to meet the stated objectives. It does not schedule additional tasks, which will increase maintenance costs without a corresponding increase in reliability protection.

Scheduled maintenance will be developed via the use of a guided logic approach and will result in a task-oriented program. The logic's flow of analysis is failure-effect oriented.

11.8.3.2 Divisions of MSG-3 Document

There are four main working portions, System/Powerplant, including components and APU's (Assistant Power Unit), Aircraft Structures, Zonal Inspections, and L/HIRF (Lighting/High Intensity Radiated Field), in the MSG-3. And each portion has it own explanatory material and decision logic diagram.

Before the actual MSG-3 logic can be applied to an item, the aircraft's significant systems and components must be identified. Maintenance Significant Items (MSI) are items, which are fulfilling defined selection criteria for which MSI analyses are established at the highest manageable level. The MSI selection process is described below: The manufacturer partitions the aircraft into major functional areas; ATA Systems and Subsystems. This process continues until all on-aircraft replaceable components have been identified. Then using a top-down approach to

establish the list of items to which the MSI selection questions will be applied. MSI selection questions consist of these four quizzes:

- Could failure be undetectable or not likely to be detected by the operating crew during normal duties?
- Could failure affect safety (on ground or in flight), including safety/emergency systems or equipment?
- Could failure have significant operational impact?
- Could failure have significant economic impact?

As long as one of the above four is answered with “yes”, the MSG-3 analysis is necessary. In addition the highest manageable level should be confirmed. After the MSI’s have been selected, the following must be identified for each MSI:

- Function(s) - the normal characteristic actions of an item
- Functional Failure(s) - Failure of an item to perform its intended function within specified limits
- Failure Effect(s) - what is the result of a functional failure
- Failure Cause(s) - why the functional failure occurs

Prior to applying the MSG-3 logic diagram to an item, a preliminary work sheet will be completed that clearly defines the MSI, its function(s), functional failure(s), failure effect(s), failure cause(s) and any additional data pertinent to the item.

11.8.3.3 Logic Diagram

This decision logic diagrams (Figures 11.33 & 11.34) are especially used for analysis of system/powerplant items. The logic flow is designed by the user begins analysis at the top of this diagram and then answer “yes” or “no” questions will indicate direction of the flow. There are two levels in the decision logic:

(1) Level 1 (questions 1, 2, 3 and 4) requires the evaluation of each FUNCTIONAL FAILURE for determination of the Failure Effect Category; i.e., safety, operational, economic, hidden safety or hidden non-safety.
Level 2 (questions 5, 6,7, 8 and 9, "A" through "F", as applicable) then takes the FAILURE CAUSE(S) for each functional failure into account for selecting the specific type of task(s).

At level 2, the task selection section, paralleling and default logic have been introduced.

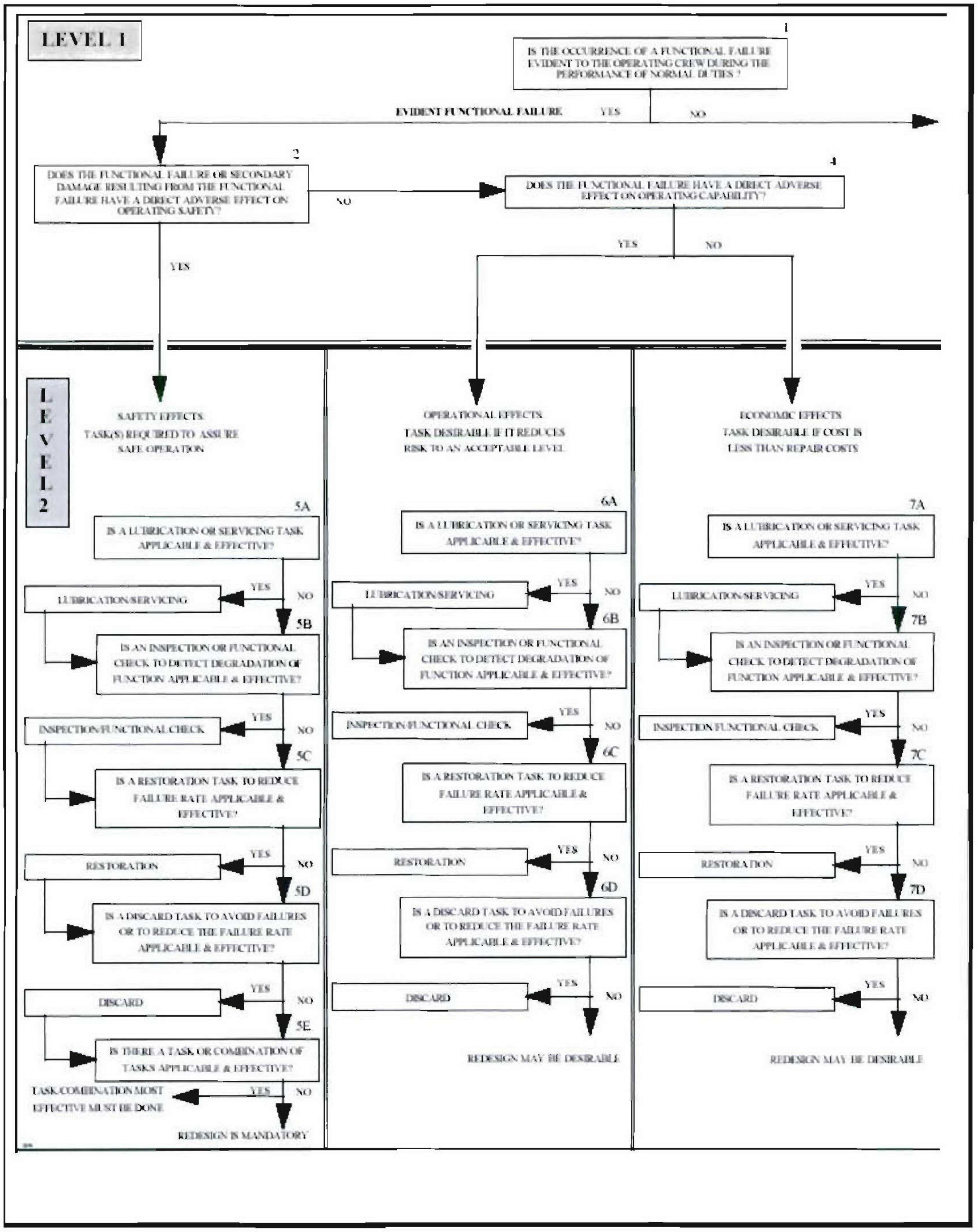

Figure 11.33: System/Power plant Logic Diagram (from Air Transport Association [2])

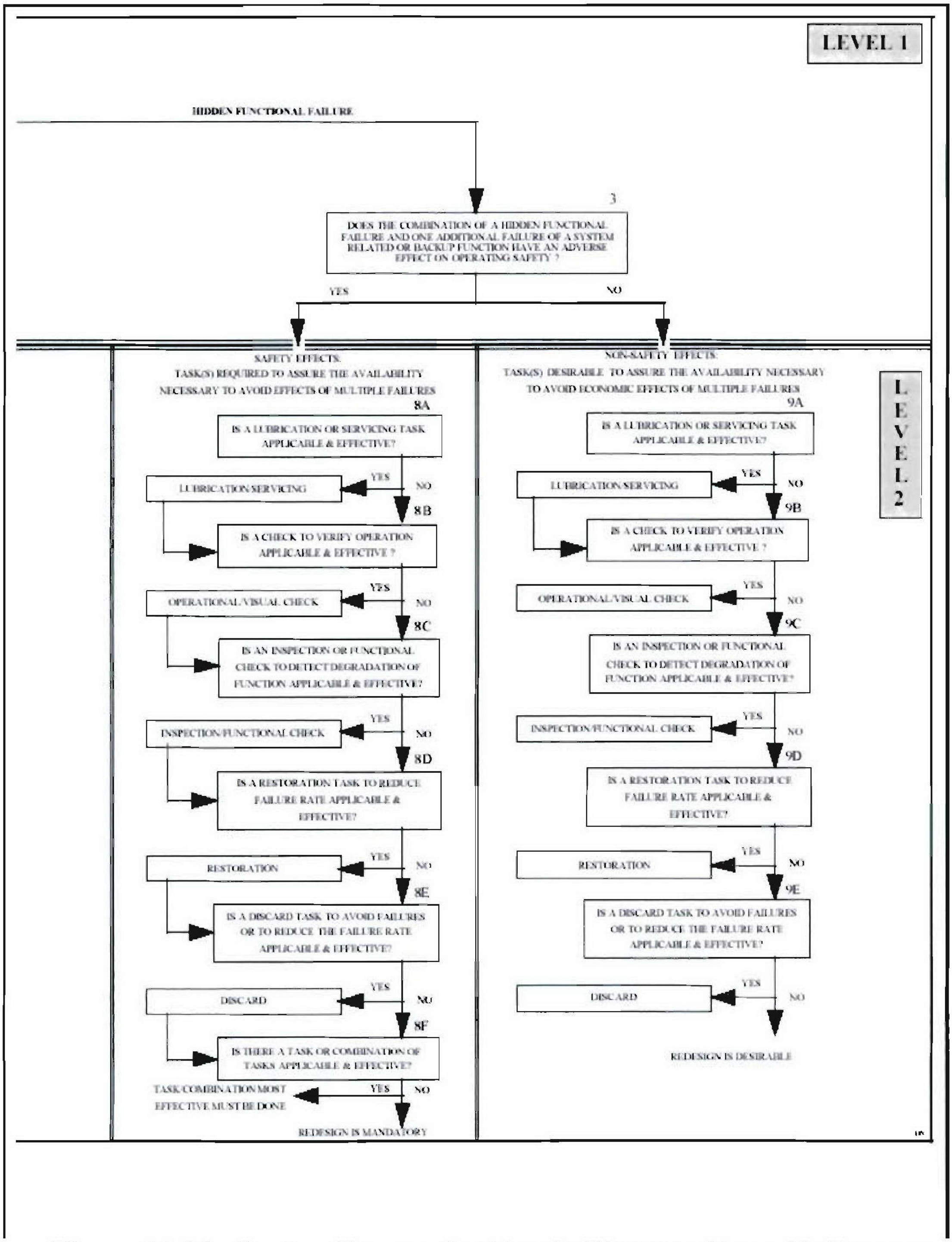

Figure 11.34: System/Power plant Logic Diagram (from Air Transport Association [2])

11.8.3.4 Task Interval Determinations

It is also a part of the MSG-3 Logic-Analysis, the MWG (Maintenance Working Group) determines the interval of each scheduled maintenance task that satisfies not only the applicability but also effectiveness criteria. The MWGs should select the most appropriate interval for each maintenance task based on available data and good engineering judgment. Here are some sources of information that can provide MWG to determine the most appropriate task interval:

- Manufacturer's tests and technical analysis
- Manufacturer's data and/or vendor recommendations
- Customer requirement
- Service experience gained with comparable or identical components and subsystems.
- Best engineering estimates

In the recent aviation industry, the most widely used task interval parameters, which measure the exposure to the condition that cause the failure at which the task is directed are:

- Calendar time
- Flight hours
- Flight cycles
- Engine/APU hours/cycles

11.8.4 Monitoring the health of the airplane engine

Monitoring the health of the airline engine fleets is a critical factor that can have a huge impact on operational viability and maintenance. Real-time information must be available to permit the successful on-wing management of engines and the planning of engine removals. With current engine health monitoring and trending technology, engines are tracked with reference to manufacturers' recommendations. Usually, this task has to be accomplished by specialist engineers in airline engineering departments or, in the case of contracted MROs (Maintenance, Repair, Overhaul), by other nominated staff. Such engineers use all available information to build up a picture of engine condition and schedule the maintenance to be performed, as their experience dictates. The decision to perform maintenance on-wing requires a very accurate understanding of an engine's specific deterioration and it will be based on an assessment of online updates of engine condition monitoring data, together with any supplemental information provided by maintenance personnel. The possibility of keeping an engine on-wing can offer significant benefits to both maintenance providers and airline operators. It can save a time-consuming engine change, the cost of leasing a spare engine and the cost of the unplanned engine shop visit. Any on-wing maintenance action prescribed by engineers should achieve the desired results

without causing any additional operational disruption, thereby avoiding further financial repercussions.

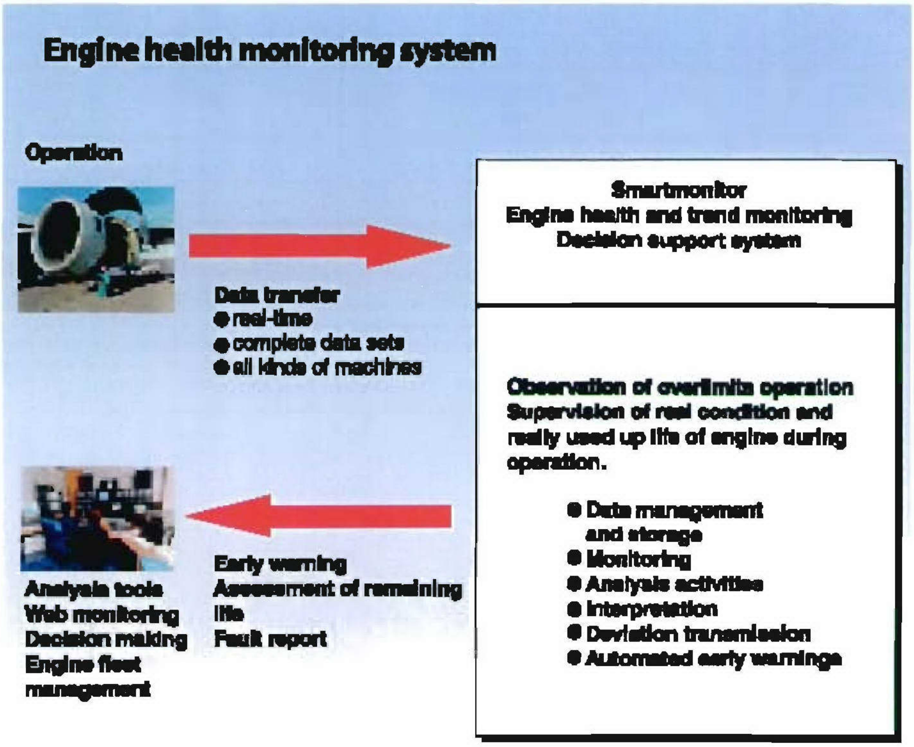

Figure 11.35: Engine health monitoring system (from William Gizzi [3])

In the recent marketplace, some commercial engine health monitoring and decision support system can fulfill the demand of automated trending and fault pattern analysis. This kind of system procures its data from an engine's existing sensor and FADEC (Full Authority Digital Engine Control) equipment, thereby introducing no additional equipment or infrastructure costs. Its pacemaker technology has "self-learning" artificial intelligence, which permits it to build a baseline model of each monitored engine, regardless of its type or its manufacturer.

11.8.5 References

[1] Aviation Today Newsstand, *"Airbus Vs. Boeing: Modern Aircraft Maintenance".*

[2] Air Transport Association, *"ATA MSG-3, Operator/Manufacturer Scheduled Maintenance Development Revision 2002.1".*

[3] William Gizzi, *"Engine health and trend monitoring developments",* Engine Year Book 2003.

11.9 Appendix: 7 –Industrial logistics applications: Penske case

11.9.1 Introduction

11.9.2 Mission of Penske Corp.

11.9.3 Maintenance program

11.9.3.1 Tasks and maintenance group
11.9.3.2 Maintenance process
11.9.3.3 Maintenance program

11.9.4 Performance and failure analysis

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11.9.4.2 Utilizing failure analysis to solve problems
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11.9.5 Application of Penske logistics and supply chain solution

11.9.5.1 Ford case
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11.9.6 References

11.9.1 Introduction

Recent announcement of retail giant, Wal-mart's push for radio-frequency identification (RFID) labels for its top 100 suppliers by January 2005 attracts much attention in the areas of logistics and supply chain management. It was only 20 years since Wal-mart required barcode for its vendors. Though Wal-Mart has not yet specified what its mandate will actually entail in terms of compliance, vendors have little doubt that the retailer is serious about meeting its deadline. Many logistics providers, third party logistics (3PL) and fourth party logistics (4PL) companies need to prepare for the technology changes in advance.

Penske, one of the largest logistics company in US, provides complete fleet management services including full service leasing, logistics, truck rentals for families and business, used trucks for sale and fleet services for utility and transit companies and municipalities. Penske can help maximize the effectiveness of transportation and distribution with proven services. They provide full-service leasing, contract maintenance, supply chain management (SCM) & logistics and truck rentals.

In this appendix, the main characteristics of logistics and SCM in Penske are demonstrated. Also, the maintenance process and procedures are investigated in order to apply the process in the other public sectors.

11.9.2 Mission of Penske Corp.

The organization of Penske covers transportation and logistics, retail automotive, automotive performance, and transportation manufacturing. The details of major functional areas or missions are summarized as the following.

- Truck leasing: full service leasing, contract maintenance, logistics and SCM, commercial and consumer truck rental, energy and telecom, and automotive delivery.
- Full service leasing: complete fleet service, rental vehicles, customer-engineered vehicles, comprehensive preventive maintenance program.
- Logistics: For Penske logistics area, there are 114 major customers operated by 13,500 vehicles including GM, Ford, Toyota etc.
- Rental automotive (Penske auto group, United auto group: 126 franchises, 30+ brands)
- Automotive performance (IRL, NASCAR)
- Transportation manufacturing (Truck-Lite, DAVCO mfg)

* IRL: Indy Racing League

11.9.3 Maintenance program

11.9.3.1 Tasks and maintenance group

As there are more than 200,000 vehicles in the Penske, maintenance is crucial for its competitive excellence. The company wants to maximize uptime through six sigma approach to maintaining the broadest range of vehicles. Major tasks for maintenance are vehicle application, vehicle purchasing, administration, maintenance operation, and systems analysis. The organization for the maintenance operation consists of 2 vice presidents, 6 area maintenance managers, 83 district service managers, 218 branch service managers, 382 maintenance supervisors, 4000+ technicians, 1150+ customer service rep's.

11.9.3.2 Maintenance process

Maintenance process is consisted of data capture, analysis, feedback, and improvement. The whole process is interrelated with each other as shown in Figure 11.35.

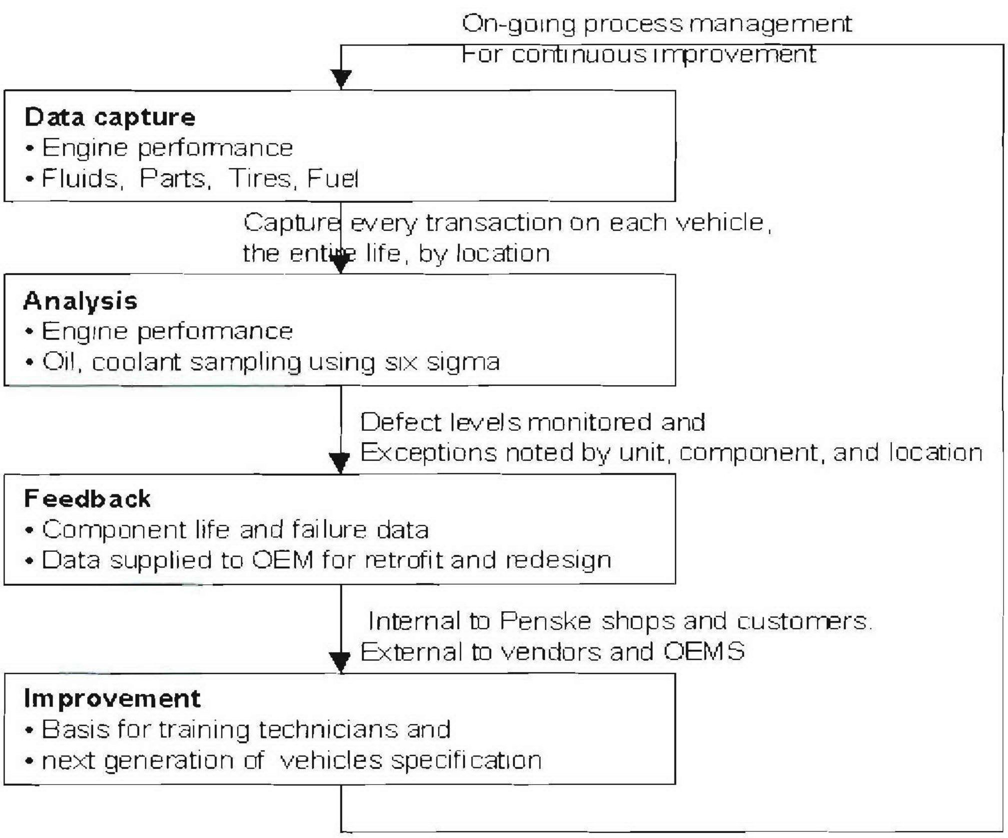

Figure 11.36: Maintenance process in Penske

11.9.3.3 Maintenance program

Maintenance programs are composed of basic preventive maintenance, fuel service, oil analysis, coolant analysis, tires, and batteries. The standards for the maintenance are shown as the following.

1) Preventive maintenance

Type of vehicle	Miles	Days
Heavy duty diesel	30,000 or	120
	And 150,000 or	455
Midrange diesel	20,000 or	180
Light duty diesel	6,000 or	180
All	60,000 or	485
Medium duty gas	8,000 or	90
Light duty gas	6,000 or	90
All non-reefer trailers	--	180
Reefer trailers	--	90
Refrigeration units-Tractors	750 hours or	90
Refrigeration units-Trailers	4,000 hours or	720
Refrigeration units-Trucks	1,500 hours or	360

Table 11.8: Preventive maintenance schedule (Source: Douglas, 2003)

2) Oil analysis program

The advantage of oil analysis program is downtime reduction, identification of premature failure, cost/mile reduction, and management tool. The details of the program are as follows.

- Sample at each inspection period
- Corrective action
- Maintenance feedback
- Monthly location reports

3) Coolant analysis

- Sample annually (PH level, Alkalinity, Freeze point, Nitrate level, Contamination, Corrosive inhibitors)
- Action gram for corrective action
- Maintenance feedback

11.9.3.4 Performance and failure analysis

11.9.3.4.1 Maintenance performance measures

- Engine analysis: % of engine cost (power plant, fuel system, cooling system, engine, air intake system, exhaust system)
- Key component analysis
  - Chassis (brakes, front axle, suspension)
  - Electrical (lighting, charging)
  - Engine (cooling, power plant, fuel, exhaust)
  - Drive train (rear axle, suspension, main std transmission)
  - Body & trailer
  - Refrigeration
  - Accessories

11.9.3.4.2 Utilizing failure analysis to solve problems

- Calculate 'rate of failure' for each part
- Tracking incidents over 5 years
- Drill down incidents by parts (See Figure 6.2)
- Manufacturer comparison for first year incidents

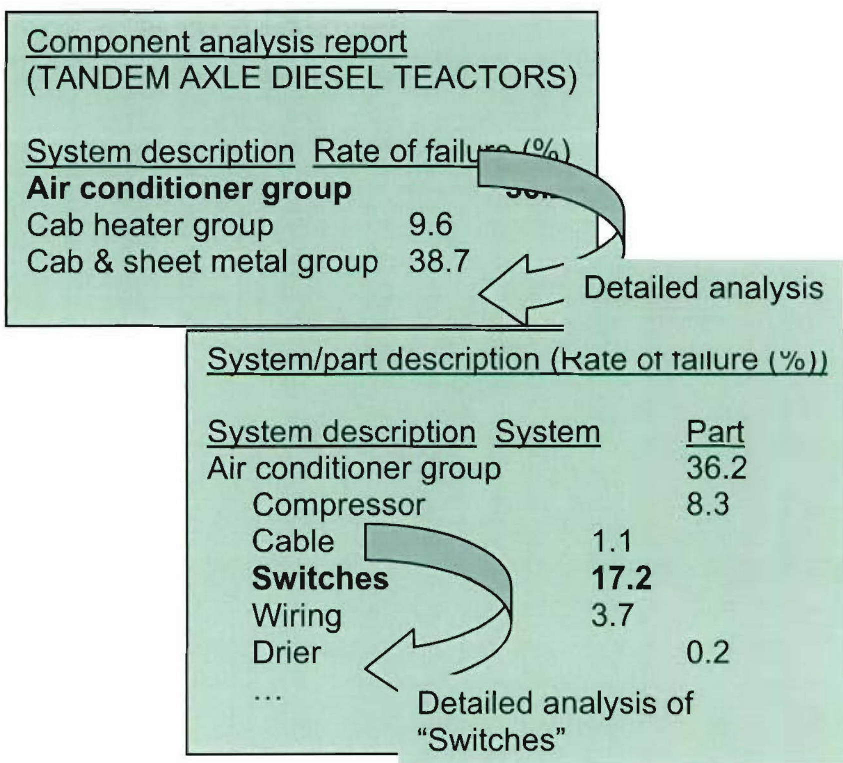

Figure 11.37: Drill down approach for failure analysis

11.9.4 Supplier measures

(1) Supplier Measurement Criteria
- Product support
- Teamwork
- Service support
- Communication

(2) Based on the above criteria, top performing vendors are recognized on vendor conference in the following areas.
- OEM
- Powertrain
- Bodies/trailers
- Accessories
- Tires

11.9.5 Application of Penske logistics and supply chain solution

The breadth of Penske's experience is reflected through their customers. Across a broad range of industries, geographies and services, Penske provides her customers with the highest possible value through our design, technology and operational execution. Success stories of Ford, Mission foods, and Whirlpool cases are summarized as the following.

11.9.5.1 Ford case

Penske partnered with Ford on several Six Sigma quality projects.
Reducing inbound carrier discrepancies: analyzing data on part discrepancies and premium costs, determining the root causes for these defects and then identifying solutions. → a 43 percent reduction of discrepancies and total savings of $970,000 for the year 2001.
The Assembly Matrix Project used Six Sigma methodologies to reduce deviations from required time on expedited shipments. → reduced deviation costs by 78 percent, saving Ford $220,000.
Parts deviations due to shipment overages. This project revealed that 15 percent of all parts deviated from plant requirements due to overages, causing additional transportation costs and productivity losses. Overages were reduced by 50 percent and with fewer overages to resolve. → $400,000 in savings for Ford.

11.9.5.2 Mission foods case

- A producer of tortillas and snacks
- By applying Six Sigma quality tools, Penske Logistics was able to reduce transportation costs for the plant by 11 percent.
- Penske delivered a 6.5 percent cost reduction per pound in transportation, and has consistently achieved over 99 percent on-time delivery at all 10 of its manufacturing plants in the United States.

11.9.5.3 Whirlpool case

- Penske helped Whirlpool redesign its network to deliver consistent, high quality service nationwide, including all trade partner channels while providing them with the tools to measure performance in a real-time environment.
- Engineered an integrated technology solution to provide fast and accurate information to speed up the cash-to-cash cycle and improve overall customer service.
- Also, established a joint process to introduce third-party business into the network, so Whirlpool's supply-chain operation can leverage other business to reduce its network costs.

11.9.6 References

[1] Douglas, Robert W., (2003). Penske, truck leasing company. Presentation material from Marine Corps logistics education program, Penn State Executive Program, Penn State Conference Center Hotel, State College, PA, June 15-27, 2003.

[2] Penske, (2003) http://www.penske.com/

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11.10 Appendix: 8 – Maintenance and Automotive Telematics

11.10.1 Introduction

Telematics is often considered a cross between telecommunications and computer systems. This includes dial-up service to the Internet as well as all types of networks that rely on a telecommunications system to transport data. For automobiles a telematics system consists of putting a computer, a wireless connection to either an operator or data services like the Internet and a global positioning system (GPS) into a car, and becomes known as Automotive Telematics. The term is further evolving to include a wide range of telecommunication functions that originate or end inside automobiles. Telematics is also being considered for monitoring purposes, but is rarely referred to in any context beside automobiles.

11.10.2 Automotive Telematics

It is important to understand the definition of what constitutes a telematics-enabled auto. From a hardware standpoint, Telematics Research Group uses the following telematics definition:

- A telematics-enabled auto has 2-way communications
- A telematics-enabled auto has a location sensing device
- A telematics-enabled auto has a control unit that is interfaced to the auto's electronic system

These three requirements define the basic capabilities of a telematics system. There are often many additional features and capabilities in telematics systems. The next table shows the telematics definition in more detail.

Must Have:	Main Approaches	May Have:
2-way communications	• Embedded cell phone • Integrated driver cell phone	• Telematics service monitoring • Remote auto function control
Location technology	• GPS receiver • Cell phone location technology	• Remote auto diagnostics • Automatic collision notification
Control unit with auto electronics interface	• Embedded telematics system for safety & security applications • Hands-free cell phone-radio integration • Navigation-cell phone-radio integration	• Crash event data recorder • Bluetooth communication • Speech user interface • On-board or off-board navigation

Table 11.9: Detail Definition of Telematics

From a functional standpoint, telematics technologies will become increasingly necessary to support the various capabilities of the automobile in the future. This is particularly true as vehicles continue their transition from analog to digital technologies. With this in mind, Telematics Research Group sees telematics evolving to fulfill the following functional requirements within the auto:

- Enabling Technology - For mobile communications, vehicle diagnostics/prognostics, safety and security, electronic toll collection, traffic management, event data recorders, and driver information systems.
- Services Platform - For content and information services that offer value to the customer including traffic reports, routing, point-of-interest (POI), customized voice portals, concierge, etc.

Automotive telematics systems will become quite complex because they involve so many different industries that make up the hardware requirements: computer, semiconductor, communications, consumer electronics and automotive industry. Furthermore, telematics will span many content and services industries such as communications, travel/mobility, weather and traffic information, entertainment, Internet and location-based services.

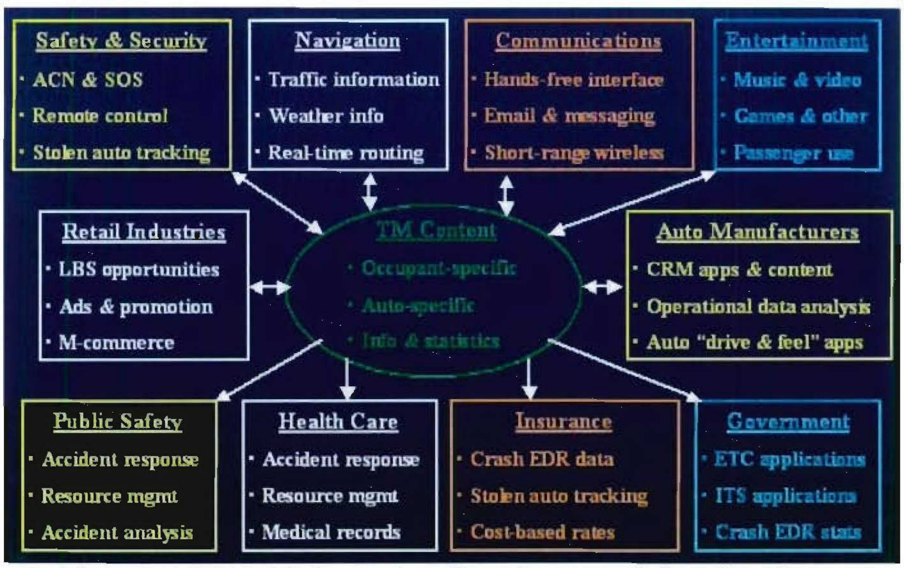


Figure 11.38: Telematics Services and Applications

11.10.3 Technologies in Automotive Telematics

11.10.3.1 Technologies for Telematics

Computer, communications and many other technology advances will have a profound impact on the telematics industry. Hence it is useful to understand technology advances and trends. The following figure is an overview of all the technologies that are impacting the telematics industry.

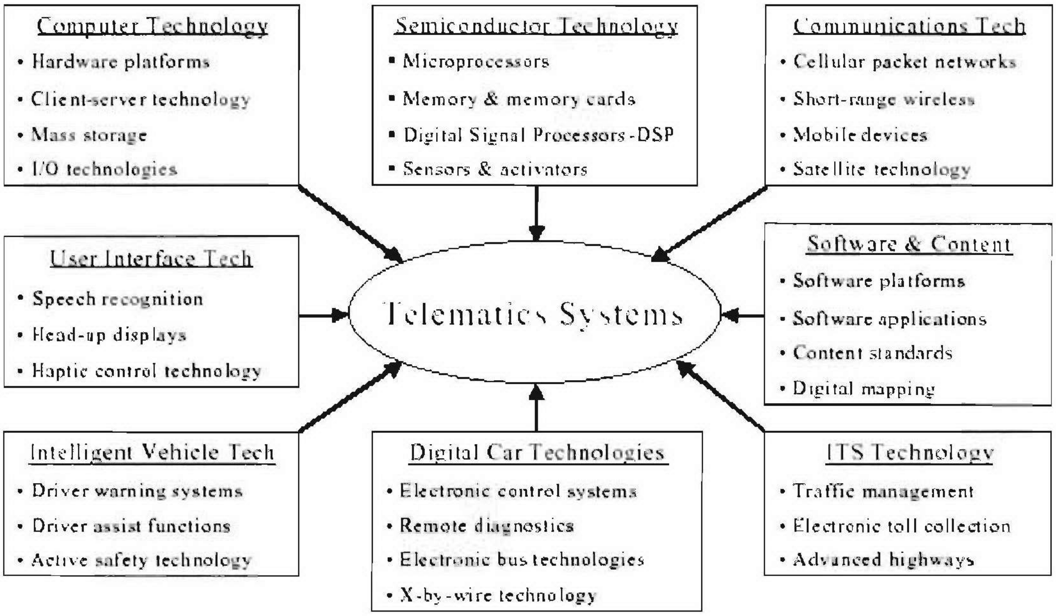


Figure 11.39: Technologies in the Telematics Industry

■ Telematics Control Unit

The telematics control unit (TCU) is an embedded computer designed for telematics functions. The user interface or HMI (human machine interface) as it is often called, may use the audio capabilities of the car radio and may have a display unit. Displays are primarily used in telematics systems that include navigation systems.

Telematics systems use a thin-client architecture for two reasons—achieve low manufacturing cost and to minimize technology obsolescence. Thin-client architecture means that the TCU has limited capabilities and limited client applications. Instead most applications need help from a remote server, which is called a client/server application.

Currently, the TCU has limited hardware and software capabilities, but this will grow substantially, based on normal computer technology improvements. To minimize future hardware obsolescence and simplify repair, TCU designs will become modular and will have field upgradeable subsystems.

■ Human Machine Interface

The HMI (human machine interface) depends on the hardware interface. The trend is towards speech recognition software as command input with text-to-speech output via the audio system.

Large color display-based user interfaces are falling out of favor due to driver distraction issues but are still necessary for many types of output. These display-based interfaces will increasingly be supplemented by auxiliary displays and driver information systems in or around the instrument cluster.

■ Electronic Technology

X-by-wire or drive-by-wire is an electronic technology that replaces the auto's mechanical and hydraulic systems. X-by-wire functionality will be used with intelligent vehicles systems and both will gain capabilities from each other's functionality. Intelligent vehicle functions are advanced capabilities that are added to traditional auto functions. Most intelligent vehicle systems are based on the use of visual sensors coupled with vast computing capabilities that recognize sensor inputs. The sensor information is used to notify the driver about potential danger or help the driver when imminent danger occurs.

■ Event Data Recorders

Limited crash event data recorders (EDRs) were introduced when airbags systems appeared to gather data on airbag operation. GM introduced EDRs with pre-crash data storage in 1999 auto models. The data from these crash recorders are manually retrieved and downloaded to laptop PCs. The data are by accident investigators, auto manufacturers and government agencies. There are federal initiatives to increase the use of crash EDRs. It is likely that crash EDRs will be mandated for use in all autos in the future.

Future telematics systems will integrate the crash EDR and will automatically transmit crash data to a central location momentarily after the crash occurred. GM is expected to be a leader in using crash EDR that automatically transmits real time crash data to a central location. As real-time crash EDR information gets distributed after 2005, the U.S. is likely to become the technology leader with positive impact for most commuters.

■ Remote Diagnostics

Remote diagnostics may be the most important telematics application for the auto manufacturers. The applications that can be built on top of regular remote diagnostics from millions of cars are likely to save the auto manufacturers lots of money. Remote diagnostics have potential savings in operational costs, warranty costs and design improvements. User-initiated remote diagnostics that will save the auto owner repair and maintenance expenditure is also expected with considerable positive CRM impact.

■ Real Time Traffic Data

Real time traffic data may be the most valuable telematics content. Japan and the European countries are further along in collecting and distributing traffic condition data than the U.S. The European traffic data are broadcast via car radios using special frequency bands. Japan has nearly 6M VICS (Vehicle Information and Communication System) receivers that receive traffic information via FM radio, RF beacons and infrared transmitters. The traffic data collection industry is improving in the U.S. Future integration with telematics systems will greatly improve in the next decade.

11.10.3.2 Emerging Technologies of Telematics Solutions

Accenture Technology Labs predicts that the emerging technologies that can be used to create these cutting-edge telematics solutions will achieve widespread adoption within the next three to five years. Several technology trends are shaping the future of telematics, and OEMs need to consider various factors that may prevent implementation of a successful telematics strategy.

■ Software Platforms

To date, telematics systems have been mainly purpose-built, meaning that everything from the system's functionality to its hardware and software to its user interface is designed to serve a specific function. Ironically, computer systems have become increasingly open, generic and flexible. OEMs will need to build telematics platforms that bridge these two worlds of function and flexibility. In addition, data warehouses, along with real-time analytics capabilities, will be necessary to capture and exploit the data generated by vehicles and their telematics applications.

■ Cellular and Satellite Networking

There are two ways to provide cellular networking in a vehicle. One is through the use of cellular models, which can be embedded directly into the vehicle. Alternatively, data connections can be established between a user's mobile phone and the vehicles' telematics system.

As newer cellular standards emerge, such as 2.5G and 3G networks, OEMs will be hard pressed to choose a potential cellular partner and decide which technologies to embed in their vehicles. Rapid advances in wireless technologies far outpace the lifespan of a vehicle. But, wireless is not the only option OEMs have for data communications. Satellite communication will continue to be more advantageous for navigation, safety and locational services as they require more reliable positioning capabilities. In addition, satellites will continue to be utilized for diagnostic applications, which require a slow and steady transfer of real-time information from the vehicle to the OEM or dealer.

■ Wireless Local Area Networks and Bluetooth

It is expected that Wireless Local Area Networks (WLANs) – with their high bandwidth, open standards and relatively low cost – will co-exist with Bluetooth technologies, which allow in – vehicle systems to communicate with one another. When this occurs, vehicular systems will no longer be self-contained. Rather, they will become part of larger Personal Area Networks (PANs), fully networked with surrounding devices and systems and synchronized with home and office computers. Furthermore, evolving peer-to-peer networks will create opportunities for vehicle-to-vehicle applications, including real-time traffic reporting and real-time performance evaluations for the same make and model vehicle – all reported from one automobile to another.

■ In-Vehicle Architecture
System designers are faced with hard choices related to the most appropriate in-vehicle architecture. They must be able to effectively manage a wide array of sensors, vehicle and communications systems. Two leading contenders for vehicle architecture include Microsoft's Windows CE for Automobile and the Open Services Gateway Initiative (OSGI) standard. A proliferation of embedded operating systems is gaining traction among OEMs; some of the options include embedded Linux, QNX and VxWorks (real-time OS for the embedded application development). Because the market is still emerging, providers should create an underlying, back-en architecture that is able to accommodate multiple vehicle architectures.

11.10.4 Telematics in Location-Based Service

Vehicles are attractive platforms for location-based services. They are inherently mobile; and many services of interest to their owners, drivers, manufacturers and even governments can be enhanced by knowing where the vehicle is and being able to communicate with it. This combination of wireless communication and location awareness will be the foundation of a wide range of products and services during the next decade.

Figure 11.40: Telematics Navigation Tool

■ Location Needs Communication and Context
Knowledge of a vehicle's location is useful, but not sufficient to deliver the highest value services. It must be augmented with two things: bidirectional communication and contextual information, such as the driver's preferences and the state of the vehicle. By 2007, it is expected that 45 percent of new vehicles include a built-in cellular modem dedicated to telematic tasks.

■ Application Opportunities
In the medium three-to-five-year time span, it is expected that the technologies such as Bluetooth to enable a tighter integration between vehicle systems and personal devices such as phones, further increasing the sophistication of potential applications. A small selection of the potential location-based (augment *location knowledge* with *context* and *bidirectional communication*) vehicle applications includes:

- Finding places and services: When it is possible to augment location knowledge with context and bidirectional communication, such applications can provide greater value to both customers and suppliers. For example, "find me a petrol station" can become "find me the cheapest petrol station that is in the general direction in which I'm traveling and that I can reach on the fuel remaining in the tank."
- Driver information: Basic driver information provided by several systems, such as phone network, in-car navigation systems and dedicated terminals have the potential to become much more sophisticated. For example, providing dynamic traffic and weather dependent routing.
- Safety and security: Accident support systems can already call for help when events such as airbag deployment are detected. However, there will be considerable further potential in the area. Combination of communication and location could provide dynamic safety information.
- Entertainment, Parking services, Pollution management, and so on.

In the longer term, location-aware, network-enabled, intelligent vehicles could suggest more radical changes to some business models. For example,

- Insurance could be charged on the basis of continuous risk assessment based on factors such as the vehicle's location, speed and use.
- Logistics could be based on dynamic rendezvous rather than static depots. Cargo vehicles could meet and exchange contents dynamically, rather than a fixed locations.
- If cars can find the location of services and direct drivers to them, products such as petrol might be supplied from mobile tankers rather than fixed stations, allowing suppliers greater flexibility and reduced real estate costs.

11.10.4.1 Technologies for Wireless Location-Based Services

Three key technologies exist to deliver location-based services over mobile network: Cell-ID; enhanced observed time difference (E-OTD); and assisted Global Positioning System (A-GPS).

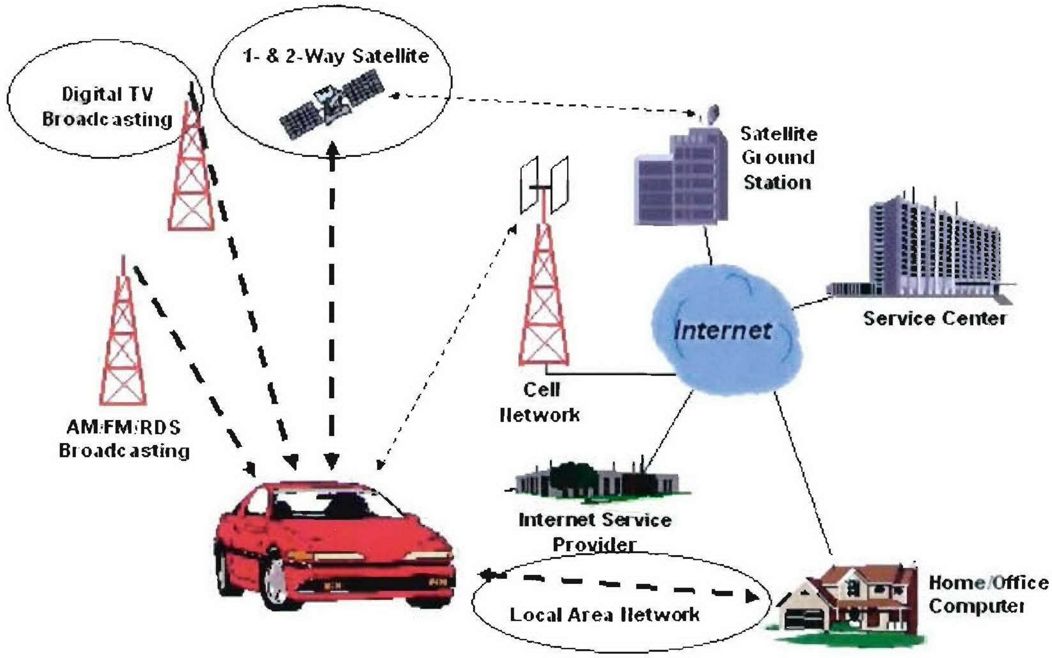


Figure 11.41: Wireless Infrastructure in Automotive Telematics

■ Cell-ID

Cell-ID is the most basic location-based technology. Using it, a mobile-network operator can determine a mobile-terminal user's location by identifying the cell site (antenna location) from which the user is accessing the network.

The accuracy of this technology depends on the density of the cell sites. In urban areas, cell sites are typically densely populated; this often gives results accurate to within 50 and 250 meters. In rural areas, however, cell sites can have a radius of more than 20 kilometers.

■ Enhanced Observed Time Difference

It measures how long it takes radio waves from two different base stations to reach a user's mobile terminal, and then locates that terminal using triangulation.

E-OTD provides theoretical accuracy of between 30 and 50 meters, but in many cases its real-world accuracy may be less than this. Nevertheless, E-OTD is a much more reliable indicator of location than Cell-ID.

A similar technology, known as observed time difference of arrival (OTDOA), will be deployed in third-generation (3G) mobile networks, for which location-based services are considered key deliverables.

■ Assisted Global Positioning System

A-GPS is a popular location-based technology for use on code division multiple access (CDMA) networks. It combines element of the Global Positioning System (GPS) with wireless-network capabilities.

As with GPS, A-GPS requires the mobile terminal to see the location satellites. However, a terminal cannot do so when inside a building or in some dense urban areas; in these case, the solution has to use cell-site triangulation as the sole means of determining location.

Like E-OTD, A-GPS capability requires extensive upgrades to network infrastructure and new mobile terminals.

■ Associated Technologies

- Short Message Service: The short message service (SMS) enables up to 160 characters of text or 140 bytes of information to be sent and received. SMS technology has been used in early location-based applications. By connecting a GPS receiver to an SMS-enabled mobile terminal (module), location information can be transmitted to the service host.
- General Packet Radio Service: General packet radio service (GPRS) is a wireless packet-based data bearer that provides an "always-connected environment. GPRS's always-connected state makes it an important technology for location-based services over GPRS for a rich end-user experience.
- Bluetooth and Wide Fidelity: Bluetooth, itself, is a short-range wireless communication technology that expected to be integrated into a wide range of wireless devices. As a result, Bluetooth may lead to easier integration between devices. Blutooth and wide fidelity (WiFi) are not intended to operate as positioning technologies, but enable location in urban and indoor area. Therefore, they complement other positioning technologies and increase accuracy. They require dense, fixed infrastructure and are best suited for "hot spots," that is, busy area where mobile device owners will congregate.

To date, the delivery of most wireless telematic services has been relatively crude, using either basic Cell-ID technology or GPS in conjunction with SMS.
One of the most common uses of Cell-ID is to provide traffic information. Most mobile-network operators enable users to dial a short code on their mobile terminal to hear the latest traffic reports By determining the user's location using Cell-ID, operators can deliver traffic information that is always relevant.
Use of GPS in conjunction with SMS has largely been limited to vertical-market applications where the productivity, customer service, security and other benefits justify the installation and deployment costs. Typically, a GPS receiver is connected to a dedicated mobile terminal to enable transmission of highly accurate location-based information.

11.10.5 Telematics & Diagnostics

Remote vehicle diagnostics (RVD) is gradually emerging as a potentially inevitable next step in the technological progression of the automotive industry, with the

promise of reduced outlay on warranty, product development and marketing acting as a compelling value proposition.

Further benefits of the emerging RVD technology will be manifested in the creation of competitive advantage through product differentiation and the ability to provide improved after-sales service and support to customers.

The advent of RVD will present vehicle manufacturers with the opportunity to step into the middle of their distribution and after-sales value chain, thus developing closer relationships with their customer base. Automotive manufacturers' retention of control over their after-sales service value chain is of strategic importance in view of the implementation of the new competition laws in Europe.

Apart from the benefits of remote diagnostics for passenger vehicle owners, the technology holds tremendous potential for cost-savings and process improvements for fleet owners and vehicle manufacturers.

However, due to the technology's nascence, vehicle manufacturers are cautious to announce ambitious plans concerning the introduction of RVD and associated services. A number of technical and commercial issues such as prohibitively high infrastructure costs, the management of technological obsolescence of component technologies and limited bandwidth, remain unresolved and must be addressed to enable the technology to fully evolve and flourish.

The nature of the remote diagnostics service is expected to evolve from passive and periodic diagnostics to vehicle-initiated fault notification and prognostics. Initially launched as a read-only option, where diagnostic trouble codes are deciphered by data center staff, it is believed that the service will make its debut in top-of-the-range vehicles in the luxury and executive segment vehicles.

The simultaneous introduction by different manufacturers - such as BMW, Fiat, Volvo, and PSA - and the benefits of the quality of the service are likely to drive the market penetration in these vehicle segments from 2003 onwards. Vehicle manufacturers are then gradually expected to introduce the service between 2004 and 2005 in the upper-medium vehicle segment as an optional feature.
Across lower segment vehicles, RVD will be available only as an optional feature over the forecast period, and installations will depend on the attractiveness of the overall package offered to the customer.

Remote diagnostics is not likely to be introduced on its own, but is likely to be bundled in a package along with other telematics services. As a result, even on the hardware front, vehicle manufacturers are expected to use the telematics unit installed in the vehicle to perform the necessary computations and communication for the remote diagnostics services as well.

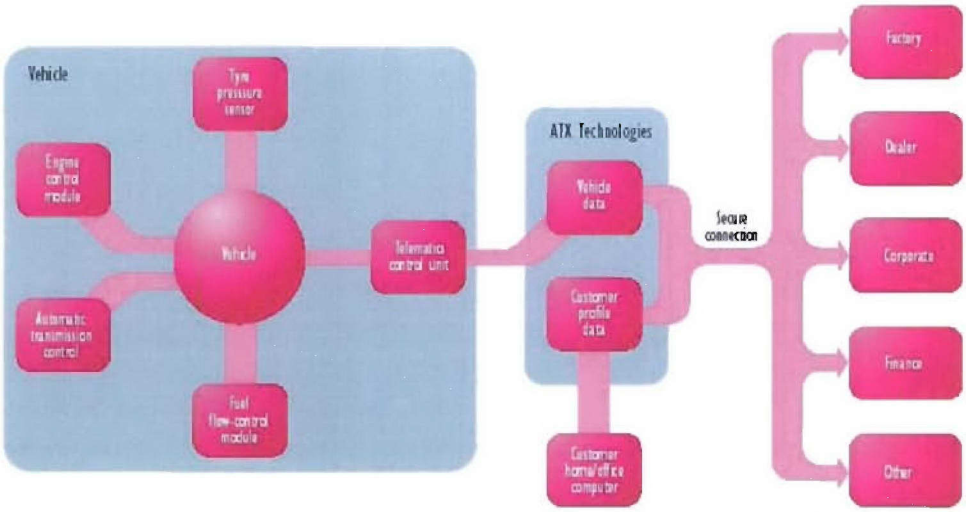


Figure 11.42: Remote Vehicle Diagnostics Telematics Service Delivery Network

- Remote Diagnostics
  - Remote Diagnostics is about sending real time vehicle data to the Telematics Service Provider continuously, so efficient vehicle monitoring can be done.
  - The TSP analyses these data to make sure vehicle are in the good condition, else an automated maintenance and repair report will be issued.
  - Vehicle Parameters: breaks, suspension, oil and other fluid levels, steering, air conditioning, engine, lights and exhaust, tire pressure, coolant, and so on.

- Controller Area Network (CAN)
  - Collect vehicle data from CAN nodes (e.g. sensors)
  - Send the vehicle data to monitoring center through the Short Message Service (SMS)
  - The real time behavior of CAN compares reasonably well to other networks. In some applications high-priority messages are transmitted within a millisecond.

- Structure of CAN
  - CAN is made up of the different CAN nodes (sensors) that connect to the CAN Bus.
  - By connecting each CAN node to the same CAN Bus, data can be transmitted and received by each node.
  - The basic structure for a CAN node will be a micro-processor, CAN controller, and CAN transceiver.

11.10.6 Case Study - GM OnStar

11.10.6.1 Introduction

OnStar is a telematics device and a subscription-based dashbord communication service created by General Motors (GM). This telematics system combines vehicle control and monitoring systems with location tracking and wireless telecommunications. The service provided numerous safety and convenience features, from emergency assistance to remote door unlocking to hotel reservations. GM also introduced that voice-activated Internet access and cellular telephone services through OnStar.

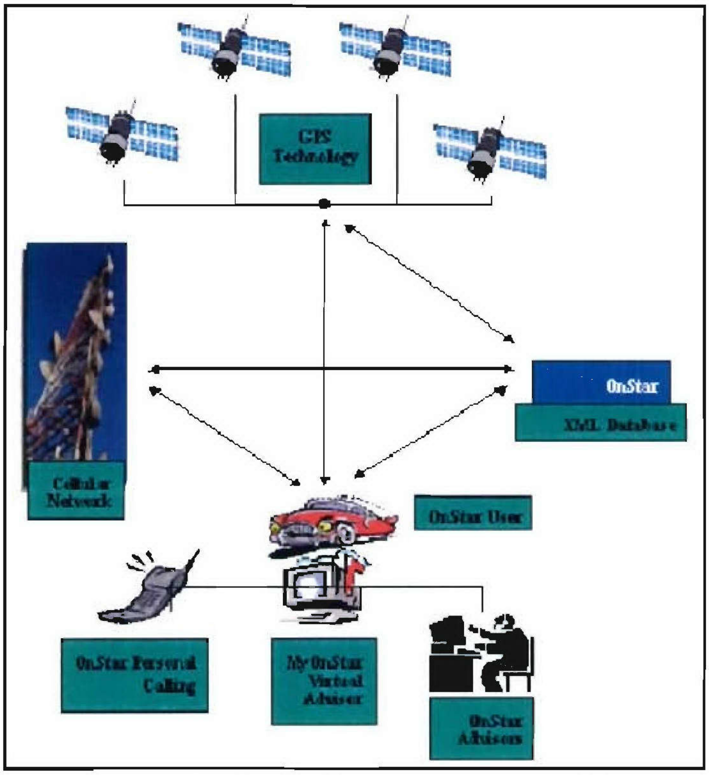


Figure 11.43: OnStar Technology Map

11.10.6.2 How It Works

Pushing one of the three OnStar buttons -- grouped on the instrument panel, rearview mirror or overhead controls -- sends a signal, via satellite, to the main OnStar headquarters in Troy, Mich. Once a signal is received, a connection is made by a live OnStar "Advisor" via cellular technology and a small speaker/mic in the vehicle. The OnStar staff is trained to answer any number of questions, from the important -- EMS calls. If necessary, they can pinpoint driver location using

GPS (global positioning system) satellite technology and give that information to the driver or the ambulance racing way.

If asked, they will stay connected and give explicit directions to the local hospital or get back on the main highway. If a car stalls, they can run an electronic diagnostic on it and tell the driver to head to the nearest dealer or wait for a tow truck. They'll even give a call if airbag deploys, checking to make sure everyone's OK and reminding that an emergency vehicle is on its way to the driver at that very moment.

Figure 11.44: GM OnStar

■ <u>How GPS and OnStar Works</u>

GPS technology works by using radio signals from 24 satellites orbiting at an altitude of 10,900 nautical miles above the earth. Each satellite calculates how long it takes a radio signal from the satellite to reach a specific vehicle, then calculates the time to do so using the speed of light (186,000 miles/s). Both the satellite and the vehicle's GPS receiver generate the same pseudorandom coded signal.
OnStar calculates the time the signal travels by comparing how late the satellite's code is with respect to the receiver. That time difference is then multiplied by 186,000 miles/s, giving the vehicle's distance from one satellite. For the most accurate measurement of vehicle location, OnStar uses measurement from four of the 16 satellites.

When communicating with an OnStar Call Center, the vehicle-identification number (VIN) and the user's account number are transmitted, as are the vehicle's make, color, and model year.

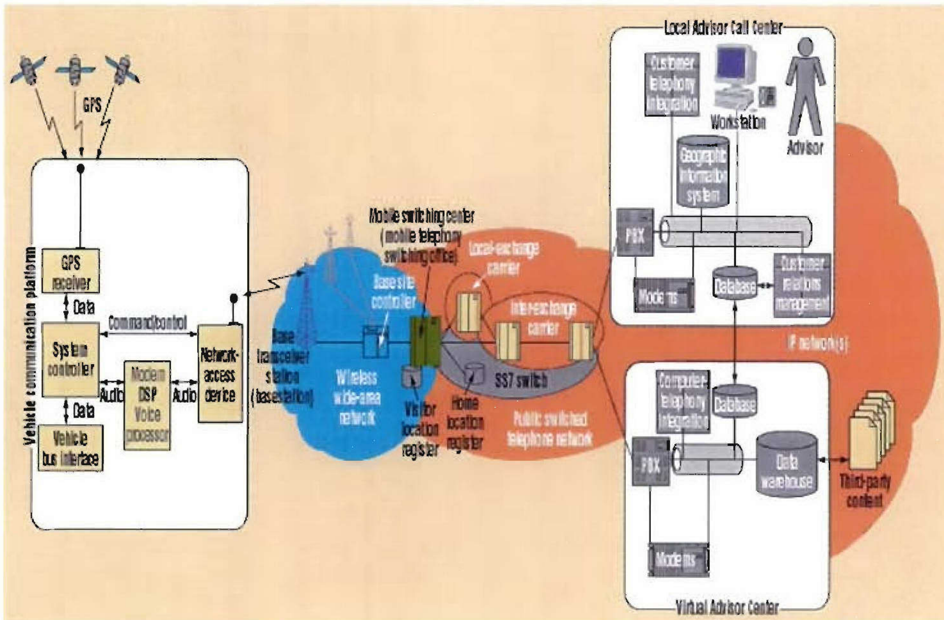
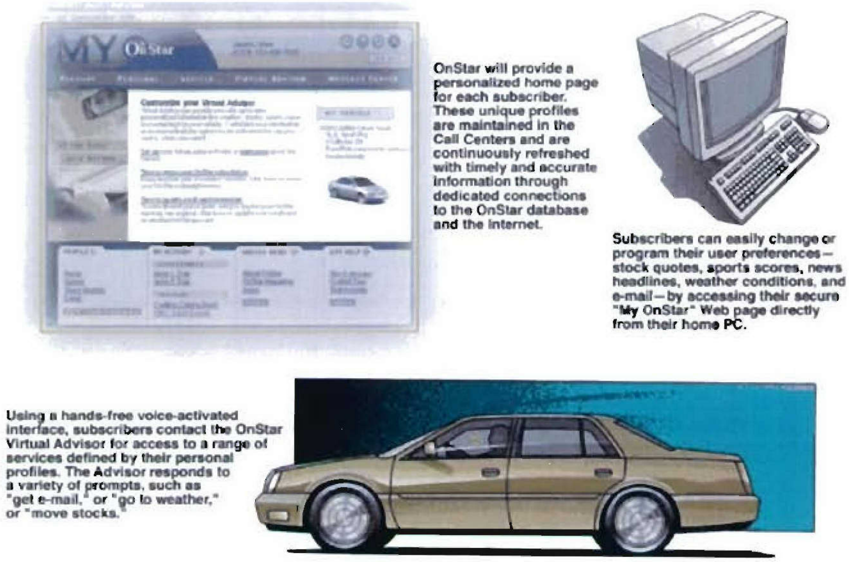


Figure 11.45: GPS and OnStar

11.10.6.3 A Closer Look Of OnStar System

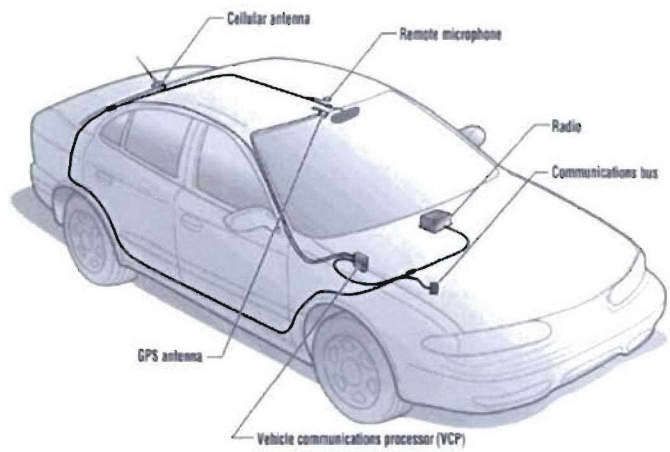
OnStar employs a three-button system (white, blue, and red) mounted either on the rear-view mirror or on the dashboard. Interactive hands-free communications takes place via a built-in cellular phone and the radio's speakers. The white-dot button is used for voice-activated cellular phone communications or connecting with the Virtual Advisor. The blue button connects the driver with a Call Center Advisor for help with a variety of services. The red button is used for emergencies. A driver's personal identification number (PIN) or a code number is used to initiate some security services such as door unlocks and stolen-vehicle location requests.



1. OnStar's Virtual Advisor service provides users with a personalized Web home page consisting of their favorite preferences.

Figure 11.46: Personalized Web Home Page for OnStar

Within the vehicle, a communications processor is located and tied to a bus, the car's radio, a remote GPS antenna, and a microphone located above the rear-view mirror, along with a cellular antenna that's mounted on the rear window, shown in below figure. Though OnStar would not specify the type of bus used, it is believed to be a CAN (controller-area network) bus. All cars and light trucks from 1996 to the present have been mandated by the U.S. Environmental Protection Agency (EPA) under the OBD II (onboard diagnostics) Act to monitor the performance of the engine's major components and emission controls. Most OBD systems use the CAN bus because it's best suited for OBD II. Analog cellular-telephone communications are implemented instead of digital for maximum geographic coverage at an affordable end-user price. OnStar plans to offer digital and analog service later.



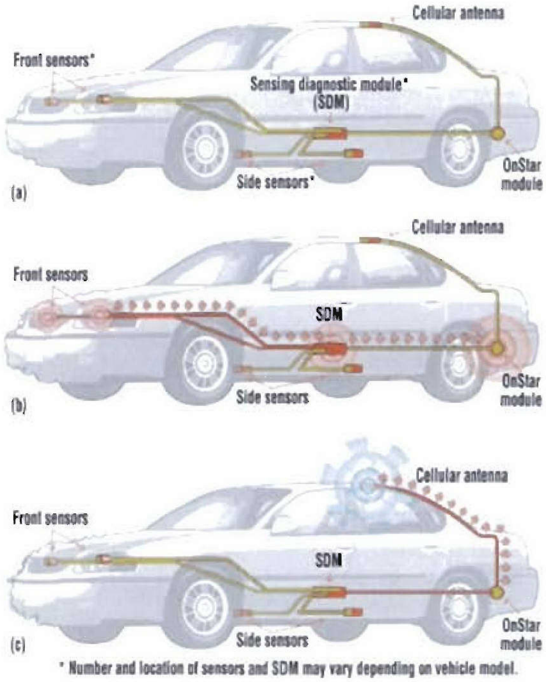
2 Shown are key components of the OnStar Interactive GPS tracking system on the vehicle side

Figure 11.47: Key Components of the OnStar Interface

The system transmits at a mobile frequency of 824 to 855 MHz. The base transmitter operates from 824 to 900 MHz. This produces 3 W of output power using an antenna.

OnStar use a 3-W high-power phone, which is much more than the typical 0.6-W output used in handheld cellular phones. That ensures that coverage is available in just about any geographic location a vehicle could conceivably be in.
Once contacted, the Call Center has the vehicle's location, vehicle-identification number, make, model year, and color and is ready to assist. Airbags on the vehicle come with sensors. Once the bags are activated, the sensors trigger a call to automatically notify the Call Center of a collision, which prompts the center to contact the vehicle, before contacting medical and emergency personnel, if necessary.

OnStar will introduce an advanced automatic crash notification (AACN) system on approximately 400,000 of its most popular 2004 vehicles, making it the first automaker to do so, shown in the next figure. The phase-in of AACN into the GM vehicle fleet will continue over several years. The new system goes beyond the ACN system already in place on the airbags. By using a collection of strategically located sensors, AACN, through the OnStar system, automatically calls for help if the vehicle is involved in a moderate to severe front-, rear-, or side-impact crash, regardless of airbag deployment. It provides crash-severity information to the Call Center operator, who relays it to 911 dispatchers, helping dispatchers determine the type of emergency service required and how fast it's necessary.



3. In OnStar's advanced automatic crash-notification (AACN) systems, front and side sensors along with the sensing capabilities of a sensing diagnostic module (SDM) plus accelerometer measure crash severity (a). For moderate to severe crashes, determined by the SDM, crash data is transmitted from the sensors to the SDM regardless of airbag deployment (b). Within seconds, the SDM transmits crash information to the OnStar Call Center, which is then forwarded to 911 dispatchers for emergency help (c).

Figure 11.48: OnStar's AACN Systems

Three different subscriber plans are available: the basic Safe & Sound plan for $199/year, Directions & Connections for $399/year, and the Luxury & Leisure plan for $799/year. The basic plan offers emergency services, automatic notification of airbag deployment, stolen-vehicle tracking (request made by the driver from outside the vehicle using a toll-free call), roadside assistance, remote diagnostics, door unlocking, vehicle alert (horns and light activation), accident/assistance, online concierge services, and hands-free voice-activated calling. The next-level plan adds route support, information/convenience services, and RideAssist help. The top plan institutes Personal Concierge Services.

11.10.6.4 GM OnStar Service

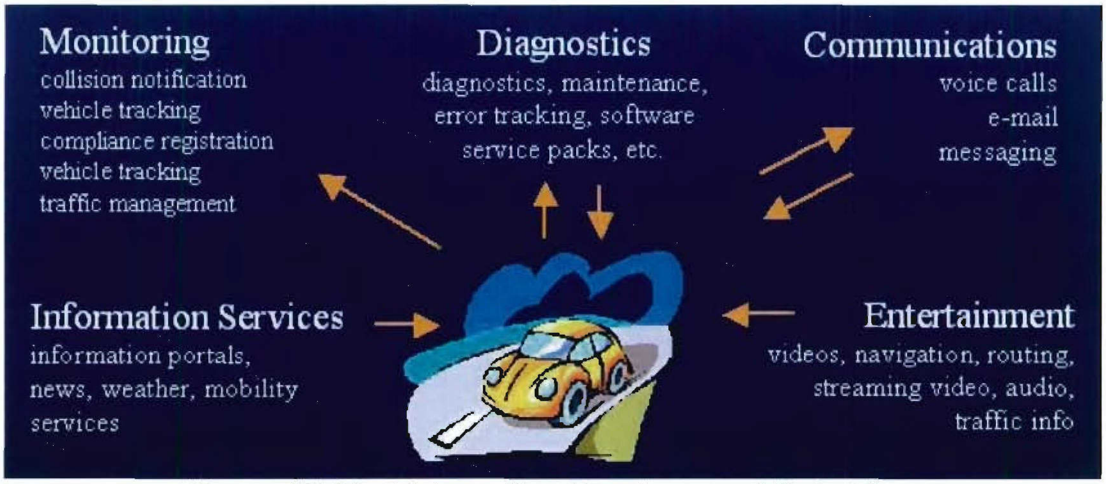


Figure 11.49: Telematics Services and Data Flow

■ <u>The Safe & Sound Plan</u>
Drive with confidence and peace of mind, knowing that when the unexpected happens, OnStar's Safe & Sound Plan provides safety and security at the touch of a button - 24 hours a day, seven days a week.

- Online Concierge Services - Access self-serve Online Concierge Services for event tickets, dining reservations, gift recommendations.
- OnStar MED-NET – personal information such as physician's name or important medical facts can be stored and provided to a hospital emergency room in the event of a serious accident.
- Automatic Notification of Air Bag Deployment - If a vehicle's airbag deploys, an emergency signal is sent automatically to the OnStar Center. An Advisor will attempt to communicate with the vehicle's occupants. If there is no response, or if the car's occupants report an emergency, the Advisor will determine the exact location of the vehicle using GPS and will contact the appropriate nearest emergency services provider..
- Emergency Services - In an emergency, the driver simply touches the emergency services button and an OnStar Advisor locates the vehicle's position on a digital map and alerts the nearest emergency services provider.
- Roadside Assistance - If a customer has mechanical trouble, a flat tire or runs out of gas, the OnStar Center will dispatch the nearest GM service provider to the vehicle's location without the driver and passengers ever having to leave the vehicle.
- Stolen-Vehicle Tracking - If a subscriber calls the OnStar Center to report a vehicle stolen, the Advisor can send a signal to the vehicle, get its location and begin tracking the vehicle. The Advisor will give the location information to the nearest police authority.

- Accident Assist - can provide step-by-step guidance after a minor traffic incident. OnStar will notify an insurance company of an accident, as well as provide a checklist of what information is needed to file a police report, or to speed an insurance claim.
- Remote Door Unlock / Lock - OnStar Advisors can unlock and lock your doors in case you locked your keys in the car, or forgot to lock the doors when you left. The Advisors can also flash your lights and honk the horn if you have trouble locating your vehicle, or to scare off unwanted individuals gathered around the vehicle.
- Remote Diagnostics - If a warning light flashes on the vehicle's instrument panel, the driver can contact the OnStar Center and an Advisor can send a signal to the vehicle asking for the status of the engine computer. The vehicle transmits any problem codes and, based on this information, the Advisor recommends the required action, which could include turning off the car and waiting for roadside assistance, scheduling a service appointment as quickly as possible, or getting the problem checked during the next scheduled maintenance visit

■ The Directions & Connections Plan

Along with everything in the Safe & Sound Plan, OnStar's Directions & Connections Plan helps you find your way - providing directions, guidance and assistance no matter where you are or where you need to be.

- Route Support - When the driver places a call to the OnStar Center to request assistance, the Advisor pinpoints the vehicle's location and provides voice-routing navigation assistance, including help to find an alternate route if the driver is caught in traffic.
- Ride Assist - user can call OnStar and request a taxi if you're incapable of driving. If no cab is available, we'll try to contact a family member or friend for you.
- Information/Convenience Services - OnStar Advisor can help with a wide array of information and convenience services, including suggesting restaurants and making hotel reservations.

■ The Directions & Connections Plan

Including all the services in the Directions & Connections Plan, OnStar's Luxury & Leisure Plan helps subscribers make the most of their drive time with a whole world of helpful Concierge Services - everything from ordering theatre tickets to making restaurant reservations.

- Personal Concierge Services - OnStar Concierge takes convenience to a new level, offering subscribers vacation planning, business assistance or tickets to hard-to-get events. A Concierge Advisor is specially trained and connected to an organization with affiliations with hotels, restaurants, entertainment companies and other service providers around the world.

■ Personal Calling
OnStar's Personal Calling provides subscribers with nationwide wireless service. This voice-activated system will dial the number and their party will answer through stereo speakers. The one-touch wireless connection and easy, hands-free communication provide them with a superior blend of safety, security and convenience.

■ Virtual Advisor
Subscriber can use the OnStar Virtual Advisor, personalized in-vehicle connection to the information driver need, when need it. Using no keypads or screens, drivers can access their information by speaking simple voice commands.

The Virtual Advisor provides up-to-date personalized information such as Financial Services, Traffic, Weather, News, Sports, Entertainment, and Email right in your vehicle. Users decide which options they'd like, as well as how and when they'd like to have these services delivered to them in their vehicle MyOnStar.com makes it easy for subscribers to set up and change their options at any time.

11.10.6.5 The Competition

OnStar is not the only technology in this area. There are competing systems for most major automakers. Mercedes-Benz uses the COMAND system, Nissan/Infiniti has the Communicator system, Jaguar has the ASSIST system and Ford/Lincoln has RESCU. But OnStar seems to have two things going for it over the others -- most of the competition's services are installed only in near-luxury to luxury vehicles and OnStar appears to offer the most bang for the buck.

The COMAND system is available only in the Mercedes S-Class models. Jaguars and Lexuses have in-dash screen systems, but they often run two grand or more and neither of those automakers are known for brisk sales to the labor market. Ford has a few models offering RESCU that get close to the middle class, but in a press release from September, 1999, Ford says some of the features of the "Intelligent Vehicle Highway System (IVHS)", like the diagnostic and active safety and warning controls, and the "Vehicle Emergency-Messaging System (VEMS)" are "next-generation technology under development." VEMS, however, is available currently in the Lincoln LS and Lincoln Continental.

Although OnStar isn't currently scheduled for base-model Cavaliers, it will be available in some moderately priced vehicles like the Blazer and the Impala. With the number of subscribers estimated to grow 2 million by 2001.

As far as features go, OnStar seems to be leading the pack. But, these services are not patentable or difficult to install in alternative products -- if someone can already give you voice response, it's a simple step to give you personalized directions. Most of the competition has navigational abilities, using either an in-dash screen or a cellular handset, but none seem to be as easy to use as OnStar.

If all goes well for OnStar and GM, this could be a major boost to the bottom line -- they may have created an effective and compelling reason to purchase a car that doesn't involve styling or mechanics.

11.10.6.6 The Future of OnStar

OnStar still has a couple of other ideas up its sleeve. News and stock quotes, red by a voice-automated system, will be personalized via subscribers' OnStar Web page. Video and audio streams also will be personalized and downloaded into vehicle players and faxing, paging and voice-mail access. Home activation of lights and security measures and grocery shopping is also on their list. There are as many possibilities as the imagination and technology will allow.

11.10.7 References

[1] N. Jones and N. Deighton, Location-Based Services and Telematics, Gartner Research, July 2002.

[2] Bluetooth and Telematics: At the Heart of the Wireless Car, Gartner Research, July 2002

[3] William McCormack and Richard R. Johnson, General Motors OnStar, Graduate School of Business Administration, University of Virginia, 2000 http://faculty.darden.edu/gbus885-00/Documents/OnStar_rev0907a.pdf

[4] http://www.onstar.com

[5] http://www.myonstar.com

[6] http://www.telematicsresearch.com

[7] http://www.accenture.com/telematics

[8] http://www.darwinmag.com/learn/curve/column.html?ArticleID=106

[9] http://www.edmunds.com/news/innovations/articles/

[10] http://www.elecdesign.com/Articles/Index.cfm?ArticleID=2825

[11] http://www.amsystech.com

11.11 Appendix: 9 – SCOR and EAI Systems

11.11.1 Supply Chain Reference Model

11.11.2 Best Practices in Supply Chain

11.11.3 Enterprise Application Integration (EAI) Practices

11.11.3.1 Introduction
11.11.3.2 Current Practices
11.11.3.3 Emerging Trends

11.11.1 Supply Chain Reference Model

The attempt to improve the performance, flexibility, visibility and readiness of a logistics chain would comprise of the following tasks. The logistics chain has to be systematically defined by specifying the different entities that make up the chain and their inter-relationships. Once it is defined its performance can be measured and evaluated using certain standard metrics. Matching the current performance of the logistics chain with the benchmarked expectations would enable us to control it by altering the relationships between the various entities within. Based on the above mentioned, philosophy the supply chain operations reference model (SCOR) was developed by the supply chain council

What is the SCOR model? – It is a process reference model entailing the set of guidelines, which help combine the elements of business process engineering benchmarking, and leading practices into a single framework Under SCOR, supply chain management is defined as these integrated processes: PLAN, SOURCE, MAKE, DELIVER and RETURN – from the supplier's supplier to the customer's customer, and all aligned with the company's operational strategy, material, work and information flows. The process elements include the following

PLAN: Assess supply resources; aggregate and prioritize demand requirements; plan inventory for distribution, production, and material requirements; and plan a rough-cut capacity for all products and all channels.

SOURCE: Obtain, receive, inspect, hold, issue, and authorize payment for raw materials and purchased finished goods.

MAKE: Request and receive material; manufacture and test product; package, hold and/or release product.

DELIVER: Execute order management processes; generate quotations; configure product; create and maintain customer database; maintain product/price database; manage accounts receivable, credits, collections, and invoicing; execute warehouse processes including pick, pack, and configure; create customer specific packaging /labeling; consolidate orders; ship products; manage transportation processes and import/export; and verify performance.

RETURN: This process element would include, defective, warranty and excess return processing, including authorization, scheduling, inspection transfer, warranty administration, receiving and verifying defective products, disposition, and replacement. In addition to these process elements SCOR includes enable elements for each of these processes. Enable elements focus on the information policy and relationships to enable the planning and execution of supply chain activities.

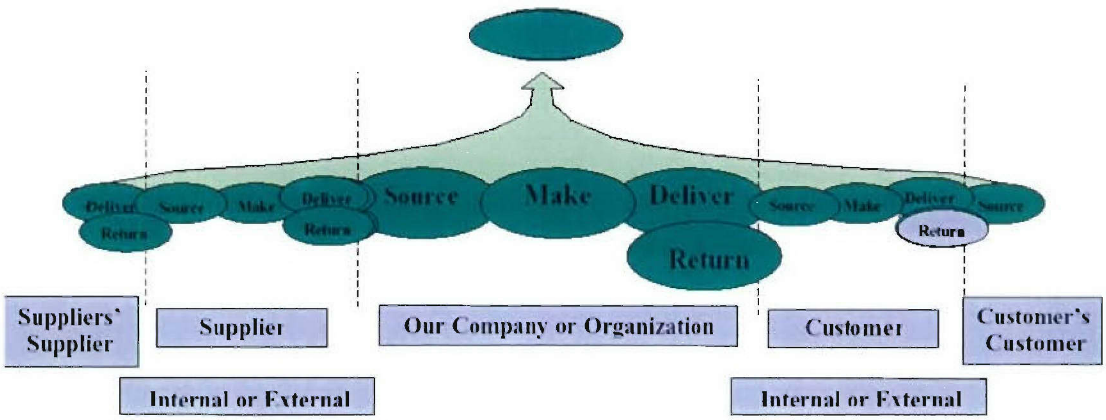


Figure 2: The SCOR Model

Figure 11.50: SCOR Model

Scope of the SCOR model: SCOR spans all customer, product, and market interactions surrounding orders – purchase orders, work orders, return authorizations, forecasts, and replenishment orders. It also encompasses material movements of raw material; work in process, finished goods, and return goods. The SCOR model assumes training of the personnel, quality of the products, information technology and the non-SCM administration. The SCOR model includes three levels of process detail. Level one defines the number of supply chains and how their performance is measured, level two defines the configuration of planning an execution processes in material flow, using standard categories like stock, to-order, and engineer to-order. Level three defines the business process used to transact work orders, purchase orders, return authorizations, replenishment orders and forecasts.

SCOR Project: Thus the SCOR project document would entail the description of existing management processes; the framework showing the relationships among these processes; standard metrics that would be used to measure the process performance; management practices that are known to produce the best-in-class performance; and standard alignment of the features and functionality. The document may include the success factors against which the performance of the supply chain would be evaluated. The success factors specified within SCOR are delivery reliability, order flexibility/responsiveness, supply chain cost effective asset management and readiness.

The definition of the supply chain using the supply chain definition matrix would form the first step to a SCOR project implementation. At the SCOR level one the focus is on the entire supply chain as a whole and the different entities are identified and the desired or to be configuration noted. The metrics that would be considered for evaluating performance would be considering the end-to-end supply chain. Once the current performance is measured the GAP analysis would help identify specific areas where the process efficiencies are much lower than the prefixed benchmarks.

The entities within the supply chain can be rearranged so as to improve the overall efficiency. The level two processes help design the material flow, the types of items and the consequent processes that are used to move the materials from one location to another are identified. The metrics used would evaluate the material flow performance. The key tools that would be used in defining the processes at level two are common sense and facts. Common sense looks at the macro issues of how the material flows within the supply chain and its relations to strategy and practices, while facts look at the processes from a micro perspective of how the materials are moved from place to place.(functional and operational details). This procedure is highly data intensive. The level three involves work and information flow analysis and design. The 'as-is' workflow is analyzed and the to-be workflow is derived in order to improve the efficiency of the supply chain. This would involve specifying the information flows across the different entities of the supply chain. The higher levels of the SCOR project would be developed as the consequence of the first three levels of analysis.

Though the SCOR model details the processes and metrics that can be adopted to define the supply chain and evaluate its performance there are some questions which are to be answered before the actual SCOR project can be initiated: Should the entire set of processes including the supplier's supplier and the customer's customer be treated as a single supply chain? Do all the supply chain threads have and end-to-end visibility? The quadrant model is a logical and systematic approach that could be used to answer the above questions.

What is the quadrant model? It is a logical technique for categorizing products and/or services, which are transported through the elements of the supply chain. The schema shows two mutually perpendicular axes, the horizontal axis corresponds to the value of the product or service towards mission accomplishment while the vertical axis qualifies the risk/uniqueness/attainability of the product/service. Based one these categories the products or services can be classified into any of these four quadrants. The first quadrant which contains the low value low risk items are categorized as routine, the low risk high value items are categorized as leveraged, low value high risk items are categorized as bottleneck and the high value high risk items fall under the category of critical. This kind of a classification of the different items and products helps to decide the amount of visibility required for that particular thread in the supply chain. It also determines the type of relationship that the company/organization should have with the suppliers/vendors of the products in those categories.

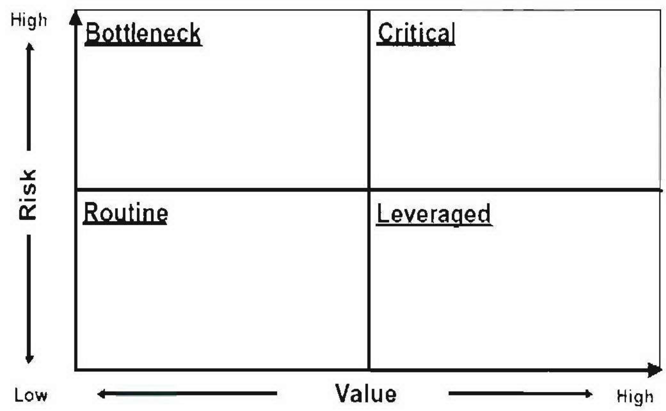


Figure 11.51: Quadrant model showing various categories

Routine: This category comprises of those products and services that are of low value and easily attainable or substitutable. In this case the buyer would have many options from potential suppliers. The driving issue in procuring these products could be cost or ease of delivery. Since these are readily available goods that buyer can avoid inventorying them to a great extent. The procurement process for these goods could be need based. Since its purchased on an as needed basis an end-to-end visibility at the supplier side is not needed. The type of relationship with these suppliers could be at a transactional level alone.

Bottleneck: These products have the same value towards mission accomplishment as the routines, but possess an element of risk in that, the number of suppliers is limited or these items cannot be easily substituted. The most important issue with these items is availability and so the buyer may store these items so as to avoid the bottlenecks developed within the supply chain. The buyer would like to have some visibility of the inventory and the delivery facilities available with the supplier. The relationship with these suppliers would ideally be a long-term relationship.

Leveraged: Low risk/uniqueness and high value characterize the items within this category, these are sometimes referred to as commodities. There would be multiple sources available to procure these items and cost and delivery would be the key issues considered while selecting the suppliers. Since these items are available from multiple sources, the buyer needs to maintain minimal inventory. The relationships with the supplier could be long term but the visibility of the this chain need to be one step more than the transactional level. For instance the available inventory information with the supplier could be made available to the buyer.

Critical: These being high-value high-risk items need to be managed carefully by the buyer. These maybe available from very few or almost one source and are not

replaceable. These items can be maintained in the inventory to sufficient levels. Moreover such critical items would need to have a full visibility of the supply chain so that decisions for procurement and the accurate delivery times can be calculated. The relationships with such vendors would be a long-term relationship and there has to be information sharing between the vendor and the buyer.

Thus the SCOR model guides us in defining, evaluating and re-engineering the supply chain at the strategic level, the operational level and the level of work and information flow. In a complicated supply chain with many nodes and numerous threads the quadrant model can be used to categorize them and thus amicably ensure visibility of the corresponding thread.

11.11.2 Best Practices in Supply Chain

In this section, we give a list of URLs which give the best practices in Supply Chain.

Grainger (LCP, xCM, xE,)

http://www.grainger.com

http://www.grainger.com/Grainger/static.jsp?page=about.html

http://invest.grainger.com/IRUploads/10160/FileUpload/branch_based_business.pdf

http://www.grainger.com/Grainger/static.jsp?page=ci_suppliers.html

http://www.darwinmag.com/read/030101/net_transformers_content.html

http://invest.grainger.com/InvestorRelations/PubCorporateOverview.aspx?partner=Mzg0TVRBeE5qQT1QJFkEQUALSTO&product=MzgwU1ZJPVAkWQEQUALSTOEQUALSTO

http://www.globalsources.com/PEC/PROFILES/GRAINGER.HTM

http://www.manufacturing.net/scm/index.asp?layout=article&articleid=CA184359

http://www.darwinmag.com/read/030101/net_transformers_content.html

Grainger established the integrated network with more than 1,200 suppliers to fulfill customer's order. Moreover, with supplier relationship management, data and information are transfer throughout the network, which can helps Grainger and suppliers manage their inventories. Grainger also offer customers the ability to order facilities maintenance products and repair parts online. Orders are placed over the Internet and transfer to one of Grainger's distribution centers for shipping or to branches for customer pick-up.

FedEx (LCP, xCM, xE)
http://www.fedex.com

http://www.fedex.com/us/about/technology/?link=4

http://users.snip.net/~gbooker/ISYS205/readings/3-Building_e-Business_at_FedEx.doc

http://www.fedex.com/us/supplychain/industrysolutions/apparel/ApparelTMS.pdf?link=4

http://www.fedex.com/us/supplychain/industrysolutions/apparel/ApparelFS.pdf?link=4

http://www.fedex.com/us/supplychain/industrysolutions/apparel/Apparelreturn.pdf?link=4

http://www.fedex.com/us/customersupport/supplychain/faq/tms.html

http://www.fedex.com/us/supplychain/industrysolutions/industrial/industrialtms.pdf

FedEx launched its Website, www.fedex.com, that allowed customers to track packages online and to conduct business via the Internet. With the real-time data transmission that assists in routing and tracking packages. Information recorded by portable bar-code scanners is transmitted to a central database and can be made available to all employees and customers.

Dell (OM, LCP, xCM)

http://www.dell.com/

http://www.dell.com/us/en/gen/casestudies/casestudy_dell_i2.htm

http://www.dell.com/downloads/global/casestudies/dell_i2_NT_global_deployment.pdf

http://www.dell.com/downloads/us/pedge/i2%20CS%20lo.pdf

http://www.intel.com/ebusiness/pdf/affiliates/i2-dell.pdf

http://www.totalsupplychain.com/Content/MAGAZINEARTICLE/SCTN/20480/103000.pdf

http://www.cc.jyu.fi/~hemi/filet/dell.pdf

http://www.dell.com/us/en/hea/topics/openmanage_om_main_main.htm

http://www.dell.com/html/us/segments/pub/premier/tutorial/order_status.html

http://ftp.us.dell.com/app/ps-i2.pdf

Dell applies the efficiencies of the Internet to its entire business. Customers can order the products by the website http://www.dell.com/ Dell also established the real time tracking system, so customers can see where their goods are situated during the travel of the products from the factory. Dell assembly the product based on the order from the customer. Since the order has been placed, all the materials are shipped from Dell's suppliers to the assembly factory. The make-to-order strategy reduces the inventory cost and also satisfies customer needs.

Penske Logistics (LCP, xCM, xPM, xE)

http://www.penske.com/

http://www.pensketruckleasing.com/

http://3plogistics.net/Site%20Visits/penske_site_visit.htm

http://3plogistics.net/Site%20Visits/Penske_LTEQ.htm

http://www.underdogconsulting.com/what_is_six_sigma.htm

http://www.isixsigma.com/

http://www.qualcomm.com/press/pr/releases1998/press937.html

Penske Logistics provides integrated logistics services to customers throughout the United States, Mexico and Canada. The wireless technology is used throughout the logistic system. For example, Penske uses satellite mobile communications systems to provide customer the visibility to track their products. Moreover, Penske also follows the Six Sigma Methodology (http://www.isixsigma.com/) to improve their operation performance.

Nabisco (LCP, OM, xE, xCM)

http://www.cpfr.org/cpfr_pdf/08_4_1_Nabisco_And_Wegman_Pilot.pdf

http://www.cpfr.org/

http://www.businessweek.com/2000/00_47/b3708071.htm

http://www.microsoft.com/resources/casestudies/CaseStudy.asp?CaseStudyID=11522

Nabisco follows CPFR strategy to share information with their distributor: Wegman. Nabisco and Wegmans exchange sales forecasts via the Web and agree on an amount to supply Wegmans. Calculations are largely based on current sales data from the checkout counter, past patterns, and upcoming promotions. The profit of using CPFR leads both companies reduce their inventory and shipping costs.

SCOR Model 5.0 (LCP, xCM, OM, xE)

http://www.supply-chain.org/

http://www.supply-chain.org/slides/SCOR5.0OverviewBooklet.pdf

http://www.tai.hut.fi/ecomlog/texts/SCOR_notes.pdf
http://www.sap.info/index.php4?ACTION=noframe&url=http://www.sap.info/public/en/print.php4/article/comvArticle-193333c63b63c8acf8/en

http://www.intel.com/eBusiness/pdf/it/pp023103.pdf

http://www.findarticles.com/cf_0/m1121/2_248/53638603/p1/article.jhtml?term=

The Supply Chain Operations Reference- model (SCOR) is a cross-functional framework that intent to integrate business process reengineering and process measurement. The main objective of the SCOR-model is to provide a language for communication among supply chain partners. This is done by establishing common metrics and process descriptions.

Sapient (xCM, xPM)

http://www.sapient.com/

http://www.sapient.com/case/usmc.htm

Sapient is the consultant company that helps a business enterprise managing their logistics and supply chains e.g. establish new enterprise workflows or architectures, customer relationship management etc. Their customers are also includes USMC logistics.

Commercial supply chain software vendors: i2 (LCP)

http://www.i2.com

http://www.dell.com/us/en/slg/topics/power_ps4q01-foreman.htm

http://www.crmbuyer.com/perl/story/20116.html

http://www.i2.com/assets/pdf/D8610BF3-D7F1-432D-B9AA6EFBC8727186.pdf

http://www.i2.com/assets/pdf/3A53A0D0-BA98-4F80-B0F76E4F0123F6B3.pdf

http://www.i2.com/assets/pdf/CSS_SEM_SRM_toshiba_css7138_0603.pdf

http://www.i2.com/assets/pdf/CSS_AER_SPM_sw_airlines_css7141_0603.pdf

i2 is the supply chain management software that helps the company mange their supply chain. i2 was created based on technologies and standards such as Extensible Markup

Language (XML), Common Object Request Broker Architecture

(CORBA ®), and Java ™. These solutions run on industry-leading application servers to provide scalability, reliability, and value to i2 ® users.

Manugistics (LCP)

http://www.manugistics.com

http://www.redherring.com/investor/2000/1024/inv-manu102400.html

http://www.crmbuyer.com/perl/story/19944.html

Manugistics is the company that provides software to help customers solving their problems in supply chain management, service and parts management, pricing and revenue optimization, and supplier relationship management. Moreover, Manugistics also provides infrastructure products, strategic consulting, and implementation services.

11.11.3 Enterprise Application Integration (EAI) Practices

11.11.3.1 Introduction

Enterprise Application Integration (EAI) comprises the challenge of efficiently linking together diverse systems and applications across the enterprise, allowing the organization to keep pace with and respond to market changes. After creating distributed monolithic, single-purpose applications leveraging a hodgepodge of platforms and development approaches through generations of technology, users and business managers are realizing the importance of seamlessly bridging them together into a single, unified enterprise application [6]. EAI addresses the above problem by allowing many of the stove pipe applications existing today to share both processes and data. With reference to the USMC project [7], these stove pipe systems refer to the various Operational Architecture (OA) functions such as request management, order management, inventory management, distribution management, and so on. These systems were typically custom built with their specific needs in mind, utilizing the technology-of- the-day. Even though the value of these applications remains fresh, many of the mission-critical systems are difficult to adapt to allow them to share information with other, more advanced systems.

The advantages of EAI are clearly evident. With the pressures of a competitive business environment, moving IT management to shorter application life cycles, financial prudence demands that increased utilization be made of existing databases and application services rather than recreate the same business processes and data repositories over and over. Another upside of EAI is that

customers are no longer frustrated as they are not required to deal with multiple stovepipe departments that had no knowledge of what the other is doing. The vast majority of corporations use several generations of systems that rely on a broad range of enabling technologies such as mainframes, UNIX servers, NT servers and proprietary platforms [6]. These technologies are all providing some value in the enterprise, but their value is diminished if they are unable to leverage other enterprise applications. Moreover, the need to integrate those systems with packaged systems has been intensified with the popularity of packaged applications such as SAP, PeopleSoft and Baan. Most software used to solve integration problems is classified as middleware, an umbrella term encompassing various communications and integration technologies. Traditional middleware addresses the EAI problem, albeit in a limited manner [17].

11.11.3.2 Current Practices

There are four distinct levels of EAI that have been identified [6,13].

Level 1 refers to point-to-point integration. It involves establishing a basic data interchange infrastructure between applications though without any real business intelligence embedded. Applications are transformed from closed to open systems, wherein many application functions are available through Application Program Interfaces (APIs). Systems are loosely coupled with a degree of application independence. Message Oriented Middleware (MOM) is a popular choice for level 1 integration.

Level 2 uses an architectural central hub or bus, which controls information exchange as opposed to point-to-point application interfaces. In addition, diverse business rules governing data and transactions between applications are now aggregated and consolidated at the middleware level. Message brokers and application servers are popular middleware choices for level 2 integration.

Level 3 integration involves a transition from the sharing the information among applications as in level 2, to actually managing the information flow between applications. Enterprise Business model is in place instead of a mere Enterprise Application Interface model. Process modeling tools, automated workflow modeling tools and decision support tools are employed at this level.

Level 4 integration refers more to the external integration of the enterprise with its partners, foreign subsidiaries, customers that facilitates the sharing and managing of information assets, usually through a common network infrastructure such as the Internet. Common data standards such as XML are employed for this purpose. Common applications at this level are B2C (e-business) and B2B.

Middleware offers transparency across networks, applications, and platforms by enabling linkages among multiple applications and databases to support flow of information and processes. It includes basic connectivity mechanisms, such as Remote Procedure Calls (RPCs), Message Oriented Middleware (MOM), Transaction Processing Monitors (TPMs), and Object Request Brokers (ORBs), as well as complex application servers and process management tools [17].

Traditional middleware offers program-to-program connectivity (Level 1 EAI) that can be enabled using RPCs or MOM (or message queuing) whereas ORBs or integration/message brokers or application servers (Level 2 EAI) could be used for one-to-many or many-to-many functionality. The former choice offers short term simplicity, however as the number of point-to-point solutions expand to accommodate increased integration among multiple systems, the long term result is a complex tangle of software pipes entering and exiting applications that are difficult to manage. ORBs and integration brokers alleviate this drawback of point-to-point connectivity by offering a "middle ground" which are capable of moving messages from any type of system to any another type by changing the format of the messages. However they are highly sophisticated and expensive requiring specialized custom coding, that significantly alter both the source and target systems to embed the middleware into the application or data store. Compounding the problem is the fact that vendors are promoting middleware suites and integration software families, enforcing the use of proprietary software standards that are only interoperable within the suite. In essence, integration brokers focus on message flows instead of technical integration, and they're too proprietary. An emerging class of integration solutions called "broker less integration" are discussed in the next section.

11.11.3.3 Emerging Trends

11.11.3.3.1 Data format of choice - XML

With XML, data can be exchanged between incompatible systems [8,10,19]. In the real world, computer systems and databases contain data in incompatible formats. One of the most time-consuming challenges for developers has been to exchange data between such systems over the Internet. Converting the data to XML format can greatly reduce this complexity and create data that can be read by many different types of applications. A lot of XML based B2B applications are under development currently. Since XML data is stored in plain text format, XML provides a software- and hardware-independent way of sharing data. This makes it much easier to create data that different applications can work with. It also makes it easier to expand or upgrade a system to new operating systems, servers, applications, and new browsers. Other clients and applications can access the XML files as data sources, like they are accessing databases. The data can be made available to all kinds of "reading machines" (agents) which is the key to a successful application integration. In order to make XML work with many kinds of databases and many kinds of data, it had to establish protocols for defining data—protocols that are platform- and database-independent. These protocols, called document type definitions (DTDs) or XML schema, have become an excellent approach to interchanging documents in an environment where neither side wants to depend on the technology the other side is using—a core problem in EDI and across e-business.

For example, Microsoft's EAI solution is based on .NET-connected software like Microsoft BizTalk Server [9,18] and Visual Studio .NET. BizTalk Server addresses

the integration problems by bringing together data across different platforms, applications and Web services. BizTalk Server was built from the ground up to support XML (eXtensible Markup Language) and SOAP (Simple Object Access Protocol), both essential for widespread interoperability and modern B2B (business-to-business) communication.

Using XML, SOAP and other core Internet protocols, BizTalk Server unites EAI, B2B and business process management functionality in a single product. Companies can then orchestrate Web services and build dynamic business processes that span disparate applications, platforms and business networks

The XML documents encapsulating your business logic should be architecture neutral (i.e., capable of delivery within a SOA (Service Oriented Architectures) or EDA (Event Driven Architectures) and over any software stack) [10]. The SOA approach consists of defining service definitions corresponding to the capabilities each application wishes to allow other systems to access. The event driven architecture involves defining a dictionary of messages which applications can either send or receive, typically corresponding to business transactions and running over messaging systems such as IBM's MQ-series. To integrate a new application, you decide which of the existing messages you will send and receive and create the necessary processing logic.

11.11.3.3.2 Broker less integration

An emerging class of solutions that offer an alternative to traditional broker-based Enterprise Application Integration (EAI) techniques and tools, is brokerless integration [11,12]. With brokerless integration, less programming is required, allowing users to focus on the business environment rather than the complexity of the application integration process Vendors like iWay have already started providing EAI products that accelerate business integration in a brokerless manner. By avoiding the excessive infrastructure, proprietary technologies, and intrusive methods of broker suites, the new broker less strategy provides the desired flexibility and return on investment (ROI) of EAI without the usual investments of money and time. Brokerless integration focuses on solving the most difficult aspects of EAI projects – the technical connectivity to applications and data and the transformations necessary to map these systems to each other.

The approach involves XML, Web services, and intelligent adapters, which provide a universal translator between applications that don't require all of the infrastructure usually included in integration broker suites. The broker less integration approach allows any IT resource to be accessed through XML documents. As a result, tools such as XML Transformation Engines can simply map from one XML document to another instead of writing custom transformation code on non-XML-based application programming interfaces (APIs). Even nonstandard systems such as legacy databases and ERP applications interact with standardized XML documents that can be incorporated into any application or business process. The broker less integration technology applies its XML capabilities to conform to the latest standards for SOAP and WSDL, without requiring commitments to specific implementations in J2EE or .NET. This allows

users of current or legacy technologies to immediately migrate them to Web services without significant changes to their architectures, high-cost consulting, or retraining. Intelligent adapters provide immediate technical connectivity to virtually any information system, including packaged applications such as SAP and Siebel, legacy data such as IMS and VSAM, and transaction systems such as CICS and IMS/TM. The adapters also validate and transform business-to-business documents such as EDI and XML, including specific industry formats such as HIPAA, HL7, SWIFT, and FIX, into XML documents [11,12].

11.11.3.3.3 Directory service – LDAP

LDAP (Lightweight Directory Access Protocol) is a derivative technology, extracted from the more complex and heavy-duty ISO/ITU X.500 global directory system [8]. X.500 was too big and cumbersome to use for the Internet and the desktop computing environment. So a "lightweight" specification was developed that uses fewer resources (memory and processor time) and is less complex to implement. LDAP is a solution to the problem posed by environments that support more than one directory service. When LDAP was introduced, most corporations were just beginning to use the directory services tied to their operating system platforms. With Novell NetWare Directory Service (NDS), Sun (Netscape) Directory Service, and now Microsoft Active Directory, it's becoming more likely that enterprise applications will be built using directory services as the repository of information about company resources such as employees, computers, data, and software. Chances are also good that most enterprises will have more than one directory service, which makes access to multiple services—most likely through LDAP — increasingly important for EAI.

11.11.3.3.4 Languages for EAI

As a language of choice for EAI, there are several excellent alternatives such as Java, C# and a recent development called Python. Python is an object-oriented high level interpreted language that is particularly suited to EAI [14]. Unlike programming languages for web services like Java and C#, Python is available on a wide range of hardware and software platforms including Sun, Intel, IBM, Microsoft Windows, Mac OS, and all Unix platforms. Python provides option for integration with low level Application Program Interfaces (APIs) for Windows and Unix platforms, making applications highly platform compatible. In contrast, Java gives the option for developing to the lowest common denominator across platforms and C# gives option to be Microsoft-compatible. Python programs can be also be extended using C, C++ or Java, or can be embedded in programs written in these languages. This portability and interoperability with a wide range of hardware and software make it a good choice for wrapping legacy applications. An open source, Python based framework and event driven network called Twisted, provides powerful, scalable and flexible EAI capabilities.

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APPENDIX 8.7

PENNSTATE

Marine Corps Research University

Interim Report 2/3

Integration of Diagnostics into Ground Equipment Study

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TO SATISFY THE REQUIREMENTS OF

MCRU Contract No. M67004-99-0037
Delivery Order No. 086

DATE

21 January 2004

Table of Contents

1 Executive Summary

The tasks performed by the PSU-MCRU team and reported in the first interim report included the following:

- A broad review of the maintenance systems in place within the USMC
- Understanding the maintenance activities as specified within the operational architecture.
- Review of the maintenance levels and categories
- Review of the maintenance related studies conducted in other DoD organizations.
- Literature review of the maintenance practices within commercial organizations.

The above information was reviewed by the PSU-MCRU team which helped in defining a scenario and the scope of the study. It is felt that a scenario will help in developing detailed specifications as we further the study. Though the scenario helps in identifying the details of IDGE at a higher level, we need use cases to drill down. In terms of technologies, Condition Based Monitoring (CBM) and Data mining will help immensely in realizing autonomic logistics. In this report we, therefore laid our emphasis on the following:

- Developing detailed use cases for the maintenance activities (Chapter 3).
- Developing data mining techniques that will supplement the use of the quadrant model so as bring greater granularity in the classification of secondary repairables (SECREPs) (Chapter 4).
- Review and analysis of condition based maintenance – with an emphasis on sensor data acquisition, processing and analysis (Chapter 5).

As a first step, based upon our understanding of USMC operations, we have developed a USMC scenario to build an integrated diagnostics for ground equipment. Our fundamental approach (for this project) will primarily focus on how a request for a part or an item gets fulfilled together with its relevant maintenance activities. A request of any kind will pass through various Marine Corps Organizational entities and experts for execution. At this stage, the envisioned scenario is equally applicable to deployment as well as to garrison. It must be noted that this scenario needs to be further enhanced based on continued discussion with USMC participants.

Envisioned Scenario for IDGE:

We considered a chaotic and hostile combat environment (deployed). Under this environment, we assume three independent companies along with a higher level centralized Force Service Support Group (FSSG). Each company consists of three platoons and a Direct Support Combat Service Support Element Detachment (CSSE Det.). Each support group has various levels of sustainment for their unit (either platoon or company) depending upon their mission.

We also assume that entities like Manpower, Tools, Inventory, and Scheduling Algorithm (SA) are among the other important features that exist within the support groups (CSSE Det. and FSSG). Manpower, Tools and Inventory will provide inputs to Scheduling Algorithms to come up with an optimal schedule for fulfilling a request.

Maintenance is an important activity in the scenario considered. We assume that there is a mobile maintenance unit for all level(s)/unit(s) to collect the damaged part(s) and disposition them for rework, repair or disposal. The organizational maintenance level is placed at the CSSE Det. and intermediate level maintenance at the FSSG.

In general, Marine Corps maintenance is organized into three categories, namely: Organizational, Intermediate and Depot level. In our scenario we consider the organizational (CSSE Det.) and intermediate level (FSSG).

Organizational level maintenance mission is to maintain assigned equipment mission ready while continually improving the process. The categories are: inspections, handling, and preventive maintenance. Intermediate level maintenance mission is to enhance and sustain combat readiness and mission capability of supported activities by providing quality and timely material support at the nearest location with the most efficient and effective resource expenditure. Intermediate level functions include limited repair commodity-orientated components and end items, job shop, bay, and production line operations for special mission requirements; repair of printed circuit boards, software maintenance, and fabrication or manufacture of repair parts, assemblies, components, jigs and fixtures.

By considering the functionalities of two levels a part can be directed to either of the two levels for rework or servicing. After rework or servicing the part is assigned to the SECREPs inventory within the maintenance unit.

At the platoon level, requests are triggered:
- By an operator (human-in-the-loop)
- By Scheduled/Preventive Maintenance (routine maintenance done either by operator or technician)
- By Diagnostics/Prognostics (by means of sensors)

Experts at the CSSE Det. assign a priority value to each of the requests entering the support service element. A request will be either for personnel, tools or parts from the inventory. Service personnel at the CSSE Det. level confirm with the manpower, tools and inventory for request availability. Different events can manifest. They are:

1. Event 1: Manpower, Tools and Inventory are all available
2. Event 2: Manpower, and Tools are available
3. Event 3: Tools and Inventory are available
4. Event 4: Manpower and Inventory are available
5. Event 5: Only Manpower available
6. Event 6: Only Tools are available

7. Event 7: Only Parts (Inventory) are available

Event 1: Manpower, Tools and Inventory are all available

Human-in-the-loop/automated system inputs manpower, tools and inventory requirement into the Scheduling Algorithm for generating feasible assignment. An operator with the required parts and tools is then sent to the specific location for replacement and returns back to the CSSE Det. with the damaged part.

The organizational maintenance operator at the CSSE Det. will assess for percentage or rate of damage on each part. After assessment, if the rate damage falls above a certain threshold value, the part is sent to the Intermediate level maintenance at FSSG for rework.

Event 2: Manpower and Tools are (only) available

The service personnel send a request to the FSSG for replenishment. FSSG personnel will check for SECREP availability. If available, the part is sent to the concerned CSSE Det. Otherwise, FSSG personnel make an order for that specific part. While placing an order, they also check with neighboring CSSE Det.'s for part availability and visibility.

If the part is available at another CSSE Det., the FSSG directs the owning CSSE Det. to send the required part to its neighboring unit. FSSG later replenishes both CSSE Dets. with the part.

Event 2 discussion is also applicable to events 3 and 4.

Figure 1.1 shows events 1 and 2 in a pictorial form. We will extend our work to events 5, 6 and 7 based upon the results from events 1, 2, 3 and 4.

We now have four different events. Our next step is how this will capture the various task descriptions assigned by our sponsors:
Task 2: Maintenance Data Implications
Task 3: Logistics Systems Information
Task 4: Establish Universal Data Support Requirements
Task 5: Identify Critical Path and Risks for One candidate system.

For the seven events listed, various issues fall into place. They are:

1) How does each platoon communicate with each other and its FSSG?
2) What kind of information is communicated?
3) What are the various maintenance data acquisition means?
4) How far can this information be sent?
5) What devices and means are required to carry out the above situation?
6) What support systems are required to assist with decision making at different levels?

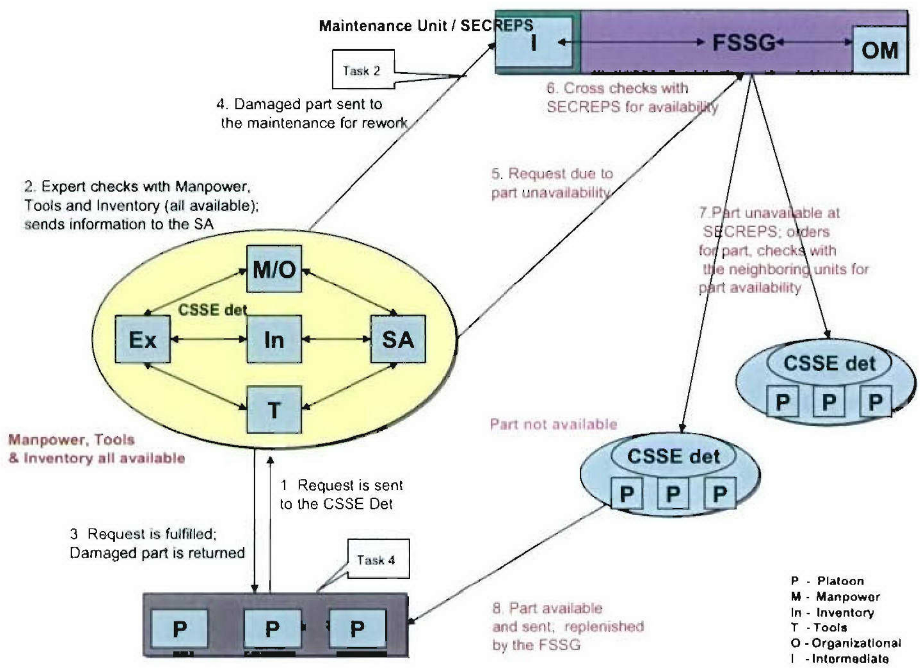

Figure 1.1: Operational View for IDGE (Events 1 and 2)

In order to address the above questions, we have studied the following:

- Use cases representing the communication amongst various nodes (supported units, supporting units) (Chapter 3)
- Data mining techniques as an enhancement to quadrant model assist decision making from a strategic point of view. (Chapter 4)
- Maintenance data acquisition using Vehicle Health monitoring systems, devices and Information Technology (IT) to enable transactions initiated by the supported units.(Chapter 5)

A Use Case represents a unit of analysis that

1. potential users can relate to and confirm,
2. designers can build and deploy,
3. implementers can test
4. project managers can use to estimate effort.

An important ancillary benefit of use cases is that they can be developed in an iterative and incremental manner for understanding requirements – which tend to be fairly fuzzy for any project in the initial stages. We have developed several use cases related to maintenance activities in USMC at various levels. In Chapter 2 we discuss the details related to Use Cases and Use Case development.

The quadrant model gives us the facility to partition SECREPS into routine, bottleneck, critical and leverage parts. However, in quad model, scientific principles for such a partitioning are not clearly explored. A scientific methodology for partitioning the

SECREPS space will help in refined application of business rules as well as developing appropriate business rules. We have developed and implemented several data mining based approaches to scientifically partition the SECREPS space. Chapter 4 contains the details of our development and analysis.

In order to trigger the autonomic logistics processes it is necessary to automate the diagnosis and prognosis processes for ground equipment health. Multisensor data fusion provides the opportunity to significantly improve the knowledge of the state of USMC resources (platforms, weapon systems, etc.). The use of a broad spectrum of sensors should improve system accuracy, decrease uncertainty, and make these systems more robust to changes in the targets and environmental conditions. Data Fusion systems seek to combine information from multiple sensors and sources to achieve improved inferences than those achieved from a single sensor or source. Chapter 5 discusses multisensor data fusion and fault diagnosis in detail.

2 Planned Work

1. Develop information flows for the seven events described in the scenario in the executive summary.
2. Develop a conceptual information architecture for the scenario
3. Understand MERIT
4. Further improve the use cases
5. Continue the work on multi-sensor data fusion/prognosis/diagnosis
6. Capture data elements
7. Work on techniques for storing and cataloging maintenance data
8. Identify candidate systems and communication technologies for implementation.

3 Use Cases

3.1 Understanding Use Cases

Use Cases are a technique that allows modeling *what* an envisioned system will do (as opposed to *how* these tasks will be accomplished with specific technologies). The initial drafts of use cases are, therefore, called *essential* use cases. These use cases capture the intended functionality of the proposed system [96].

Typically, use cases are written using terminology that is familiar to the potential users. The use cases then allow the system architects and future designers the opportunity to scope the project and give it structure.

A single Use Case, thus, represents a unit of analysis that (a) potential users can relate to and confirm, (2) designers can build and deploy, (3) implementers can test, and (4) project managers can user to estimate effort.

An important ancillary benefit of use cases, therefore, is that they can be developed in an iterative and incremental manner for understanding requirements – which tend to be fairly fuzzy for any project in the initial stages.

Definition: A use case is a scenario that yields a result of measurable value to an actor.

An actor is a role played by a potential user. A use case is, thus, documented as a description of interactions that an individual actor will carry out with a system.

The use case technique is part of what is known as the Unified Modeling Language (UML), which has become the de facto standard for specifying information systems [97].

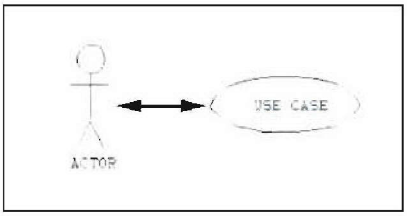

Figure 3.1 Primary Use Case Notations

The primary notations for use cases include the Actor (stick figure) and the use case (oval) (see Figure 3.1 above). In addition, the functional groupings of use cases are sometimes referred to as packages (see Figure 3.2 below).

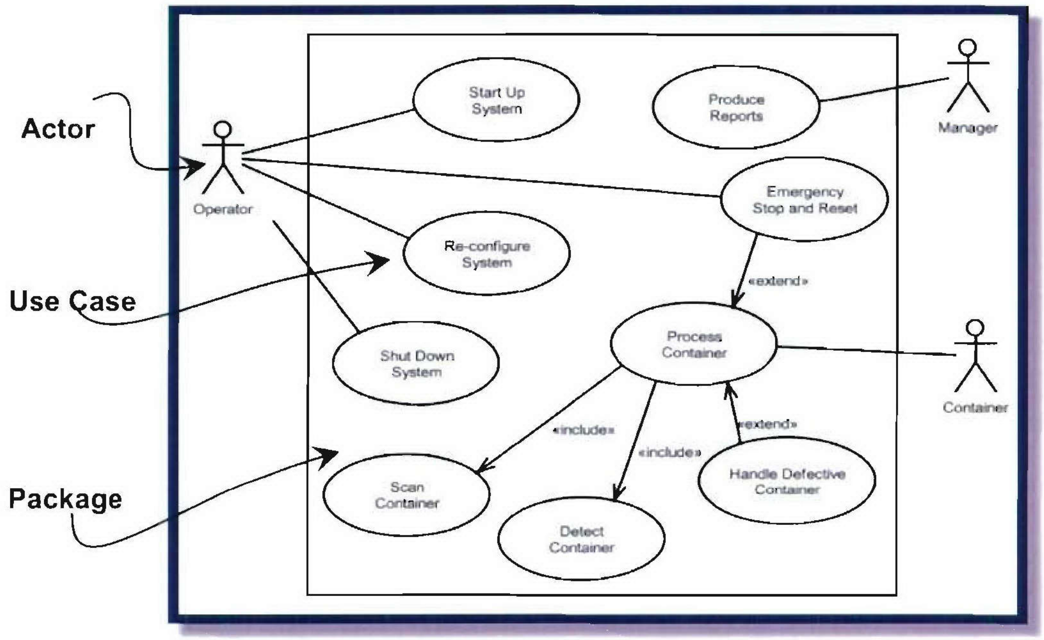

Figure 3.2 An Example Use Case Diagram

Use cases, thus, provide a vehicle for communicating with the developers by identifying scenarios of value to the users, and provide a tool for envisioning and architecting that can be used to communicate with both, the system developers and system users.

Keeping these objectives in mind, generally, use case steps are written in an easy-to-understand structured narrative using the vocabulary of the domain. This is engaging for users who can easily follow and validate the use cases, and the accessibility encourages users to be actively involved in defining the requirements.

3.2 Using Use Cases to Envision IDGE

For an open-ended problem such as the proposed IDGE initiative, use cases represent an indispensable tool precisely because of its vague, ill-structured, futuristic focus. The myriad of actors involved in the system need to make their perspectives clear. The research team needs a technique that they can use to understand and envision the envisioned IDGE effort in terms of meaningful chunks. These requirements make use cases the appropriate choice for envisioning IDGE.

With the use cases, IDGE also inherits a rich stream of research and a strategy that the research team can follow to track progress, and integrate various elements. A simple statement of this strategy is shown below.

1. Define the problem informally in the domain of interest
2. Develop an informal strategy for the domain of interest

3. Formalize the strategy as use case chunks
4. Use the use cases to identify information of interest
5. Clarify specifications

It is the very simplicity of use cases that makes them so powerful. The steps can iterate a number of times as the outcomes of each inform the next step as well as the overall process. The steps are instantiated for the IDGE below.

- First, the problem can be defined informally to start the process. In the case of the IDGE system, this can be articulated as application of the autonomic logistics concept for ground equipment to ensure better maintenance of ground equipment.

- Second, an informal strategy can be developed for the domain of interest. In case of IDGE, this involved choosing the LAV as an exemplar to make the discussions concrete, and scoping the discussion by the OA processes (on the top-side) and the sensor architectures (on the bottom-side).

- Third, the strategy can be formalized as use case chunks. Identification of use cases thus requires chunking the functionality of the envisioned system into cognitively and pragmatically manageable units. For the IDGE, this means understanding different roles (actors) and how they will interact with the proposed system at different times and to achieve different goals.

- Fourth, the use cases can be used in a manner that directly addresses concerns of interest. For the IDGE, the immediate concerns of interest are the data implications and the universal data requirements. These can be tagged to the use case descriptions to identify the data implications of each use case.

- Finally, the specifications can be formalized to the extent possible so the process can repeat.

For the task of understanding data implications of the proposed system, use cases, therefore, provide an excellent jump-off point. They allow the research team to clarify the requirements of users. These requirements can then be translated into specific data implications. Finally, the frequencies of use of these scenarios can be used to compute the data storage, transfer and communication implications.

Over the last few months, multiple iterations were done to identify a first set of use cases for the IDGE. These are described next.

3.3 A Top-Down View of Proposed Use Cases for IDGE

Whereas use cases provide a window on the scenarios that will be part of the proposed system, another perspective is also necessary to complement this view. This perspective is the architectural perspective. Here, architecture refers to the arrangement of roles, hardware and necessary network connections that are typically distributed over a geographical area.

For the proposed IDGE system, a preliminary architecture can be tied to the manner in which the organizational levels can be identified. These include the following levels:

- The Vehicle Level (in our exemplar, the LAV)
- The O-Level (connecting to the Battalion level and the vehicle level)
- The I-Level (connecting to the MEB and the MEF)
- The D-Level (connecting to the MEF and the Sea-Base

In addition, connections are shown to the OA processes. Figure 3.3 shows the preliminary architecture for IDGE.

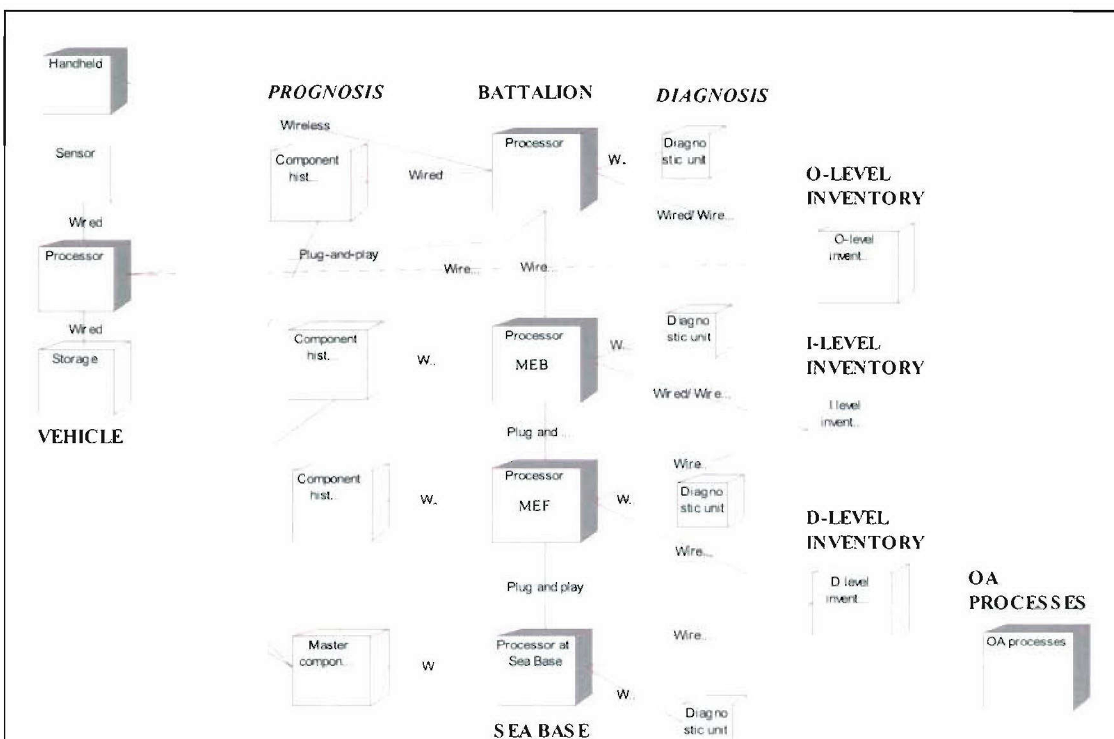

Figure 3.3 A Preliminary Architecture for IDGE

The figure shows the Vehicle level on the left hand side, and the three levels – O-level, I-level, and D-level in the centre. Towards the right, it depicts the connection to the OA processes. The cubes shown in the figure indicate either Processors or Devices.

These notations are part of the Unified Modeling Language (UML) indicated earlier. The above diagram and the diagrams that follow were created using a Computer Assisted Software Engineering (CASE) tool called Rational Rose™ that implements this language (UML) [98].

Following this preliminary architecture, the use cases and functional groupings were created. Figure 3.4 shows this overview.

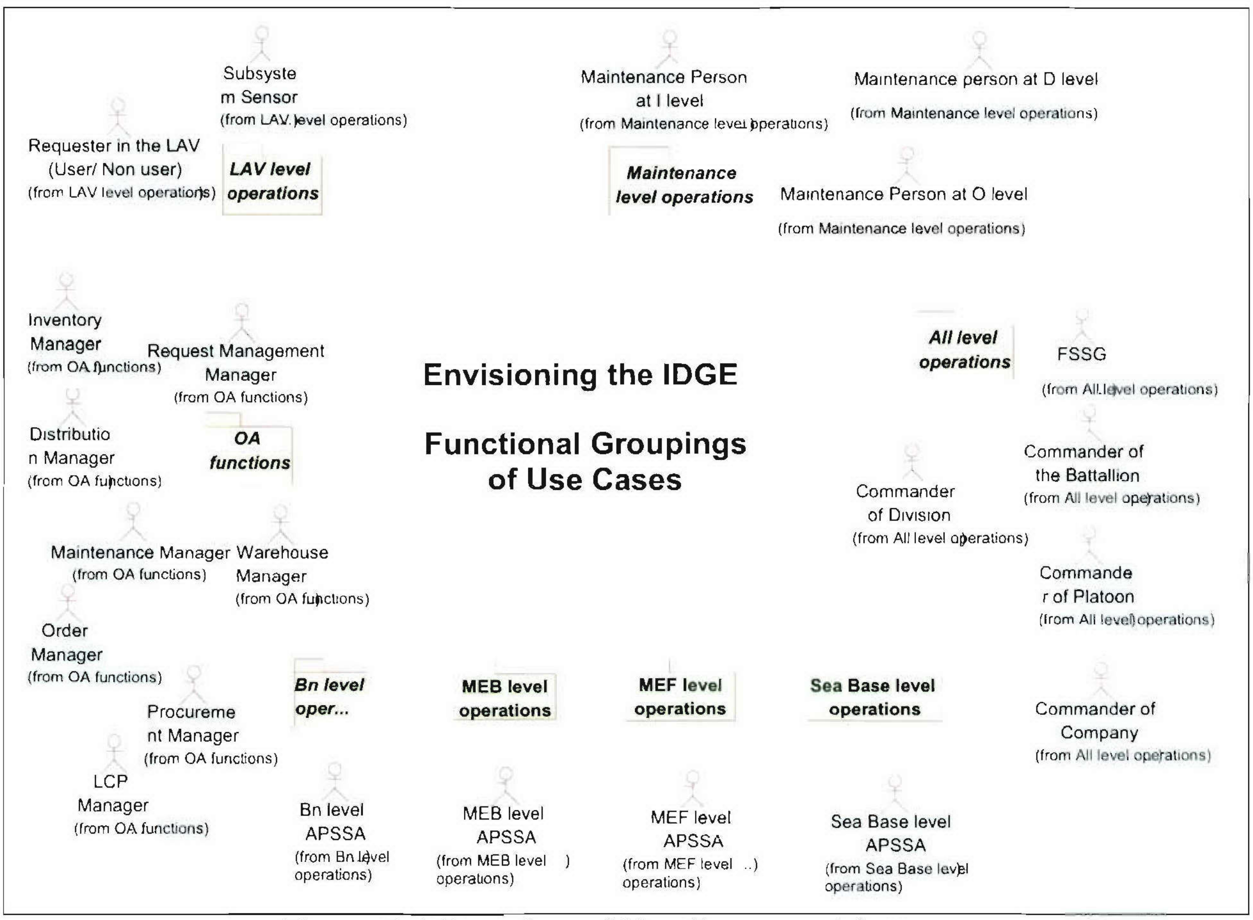

Figure 3.4 Overview of Use Cases and Actors

The figure shows that the overview contains several Packages i.e. functional groupings of use cases that map to the different levels indicated in the architecture (see Figure 3.3 earlier).

The figure also shows that several actors that identified during this process. Each of these actors represents a role that may be played by a person or an information system. For instance, the actor "Maintenance Person at D Level" captures the role that a person or group of persons may fulfill for performing maintenance at the D-level.

Table 1 below shows the list of actors identified. Complete definitions of each Actor are provided in Appendix 3.1.

Table 3.1 List of Actors Identified

Actor
Commander of Company
Commander of Division
Commander of Platoon
Commander of the Battalion
Battalion level Active Passive Sensor Signal Analyst (APSSA)
Requestor in the Vehicle (User/Non-User)
Subsystem Sensor
Maintenance Person at D-Level
Maintenance Person at I-Level
Maintenance Person at O-Level
MEB Level Active Passive Sensor Signal Analyst (APSSA)
MEF Level Active Passive Sensor Signal Analyst (APSSA)
Distribution Manager
Inventory Manager
LCP Manager
Maintenance Manager
Order Manager
Procurement Manager
Request Management Manager
Warehouse Manager
Sea Base Level Active Passive Sensor Signal Analyst (APSSA)

3.4 Documenting Individual Use Cases in the Functional Groupings

Following the identification of functional groupings (see Figure 3.4), individual use cases were identified in each functional grouping, and documented. This resulted in a large number of use cases, which were then examined to identify possible combinations, overlaps or problems. This iterative process resulted in a total of 25 use cases. Table 3.2 below shows titles and brief descriptions of these use cases.

Table 3.2 List of Use Cases Identified

	Level	Use Case	Brief Description
1	All levels	Read component history database/ View diagnosis results	To allow actors at various levels to log into component history database to read a comprehensive history report of the component viz. diagnosis results, expiry dates, threshold alarms, past troubleshooting actions such as replacement, repairs etc. Also contains further information regarding identity codes etc. This is a purely Read-Only operation and does not involve any writing into the database.
2		Prognosis of LAV	To monitor the health of an LAV on the whole based on the health of its constituent subsystems
3	Battalion level	Authenticate received signals at Battalion	To authenticate the source of sensor data stream/ PDA form received from the LAV level to ensure that it originates from validated LAVs/ personnel.
4		Process PDA form at Battalion level	To analyze the information received from the PDA that gives further description about the failure (or impending failure) of a subsystem, in order to diagnose the problem successfully.
5		Escalate diagnosis to MEB from Battalion	To upload sensor data stream/ Bn level diagnosis results and also ship faulty subsystem/ component from Bn to MEB, so that MEB can assist in diagnosis
6		Diagnosis of subsystem at Battalion	To diagnose the health of a subsystem at Bn, based on information/ inventory received from LAV to determine component that has failed/ will fail (source of information could be PDA form/ sensor data stream)
7		Trigger maintenance action by O level	To trigger initiation of maintenance action by the O-level maintenance (given by Bn level)
8		Query a sensor	To ping/ trigger the LAV system processor to upload a subsystem sensor data stream, if it did not take place at the scheduled instant.
9	LAV level	Report out of ordinary event	To send PDA form from LAV to Bn in order to seek assistance from Bn level in troubleshooting/ diagnosis of faulty subsystem (LAV mechanic unable to resolve problem by himself)
10		Diagnosis of subsystem at LAV	To diagnose the health of the subsystem by LAV mechanic, in order to determine the component that has failed/ will fail, once thresholds are breached by the subsystem sensor data stream

	Level	Use Case	Brief Description
11		Subsystem troubleshooting assistance/ Escalate diagnosis to Bn level	To decide the flow of information/ inventory that will assist LAV mechanic in subsystem troubleshooting i.e. LAV to Bn (shipping of secondary reparable) or Bn to LAV (Bn mechanic assistance or shipping of replacements).
12		Prognosis of subsystem at LAV	To monitor the health of an LAV subsystem by analyzing the data stream from the subsystem sensor to detect breach of thresholds
13		Upload data stream periodically to Bn level	To upload the sensor data stream at periodic intervals from the LAV system processor to the Bn level system processor
14	Performing Maintenance	Condition based maintenance action at appropriate level	For CBM the maintenance action is performed when the impending failure occurs. The processor unit from the LAV detects the abnormalities of the subsystem or component. The diagnostic unit from the corresponding organizational level queries information from the LAV and indicates the fault. Moreover, it guides the LAV to the appropriate maintenance level.
15		Report Maintenance action/ Update component history	To record the maintenance action taken at appropriate level which will then update the component history database.
16		Take corrective maintenance action	To perform corrective maintenance at appropriate level after the component or subsystem failed.
17		Trigger request management	To trigger request for components/ inventory to external suppliers S1 and Sn by either maintenance levels or Sea Base level.
18		Take preventive maintenance action	To perform preventive maintenance action at appropriate level on components/ subsystem before they actually fail. Such components need to be checked or repaired periodically in advance based on expiry dates and so on.
19	MEB level	Diagnosis of subsystem at MEB	To diagnose the health of a subsystem at MEB based on information/ inventory received from Bn to determine component that has failed/ will fail
20		Trigger Maintenance action by I level	To trigger initiation of maintenance action by the I-level maintenance (given by MEB level)
21	MEF level	Trigger maintenance action by D level	To trigger initiation of maintenance action by the D-level maintenance (given by MEF level)

	Level	Use Case	Brief Description
22		Diagnosis of subsystem at MEF	To diagnose the health of a subsystem at MEF based on information/ inventory received from MEB to determine component that has failed/ will fail
23		Escalate diagnosis to MEF from MEB	To upload sensor data stream/ MEF level diagnosis results and also ship faulty subsystem/ component from MEF to Sea Base, so that Sea Base can assist in diagnosis
24	OA Processes	Trigger request management	To trigger request for components/ inventory to external suppliers S1 and Sn by either maintenance levels or Sea Base level.
25	Sea-base	Diagnosis of subsystem at Sea Base	To diagnose the health of a subsystem at Sea Base based on information/ inventory received from MEF to determine component that has failed/ will fail

The use cases were part of different functional groupings. The following figures (3.5 to 3.12) show how these use cases were part of the different functional groupings. Each figure shows the use cases identified at that level.

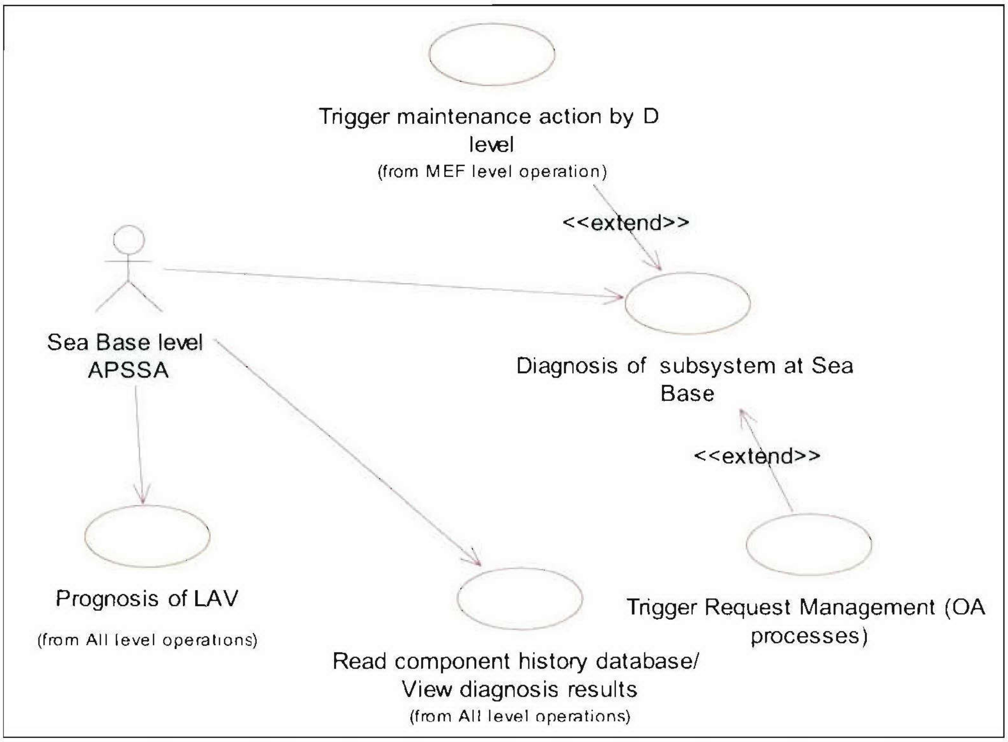

Figure 3.5 Use Cases for Sea-Base Level Operations

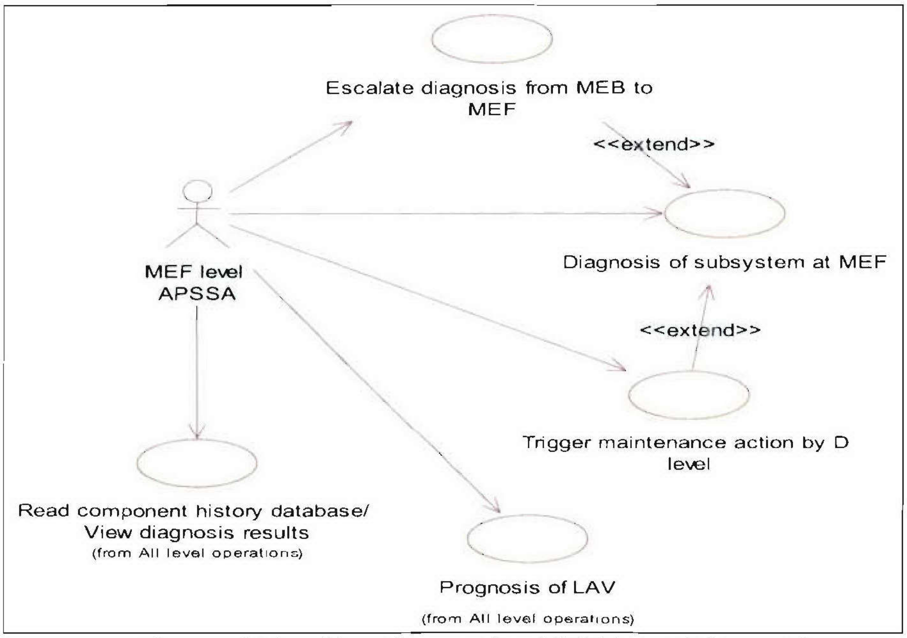

Figure 3.6 Use Cases for MEF Level Operations

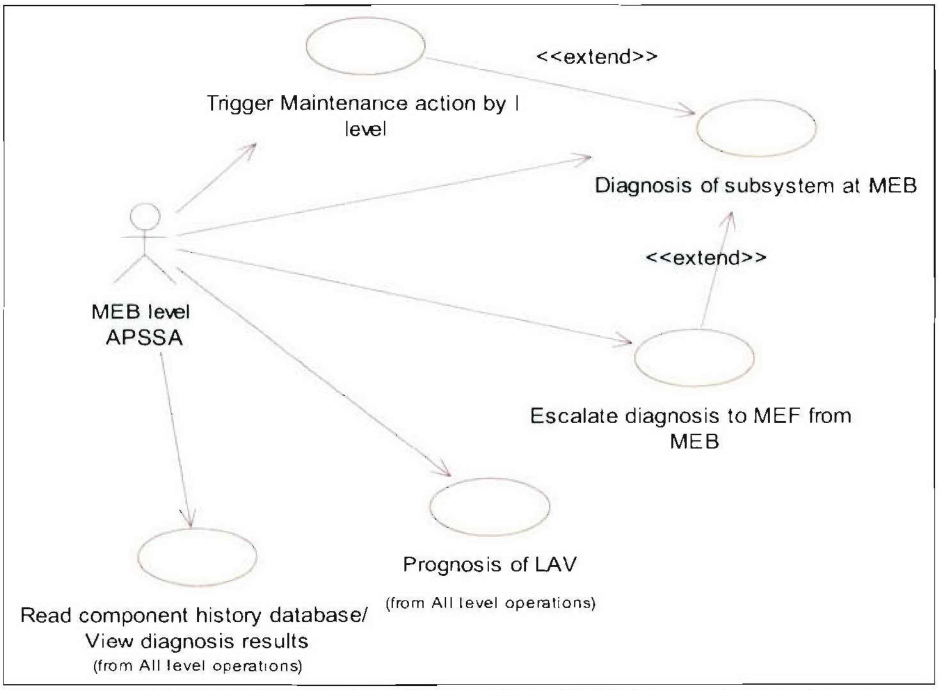

Figure 3.7 Use Cases for MEB Level Operations

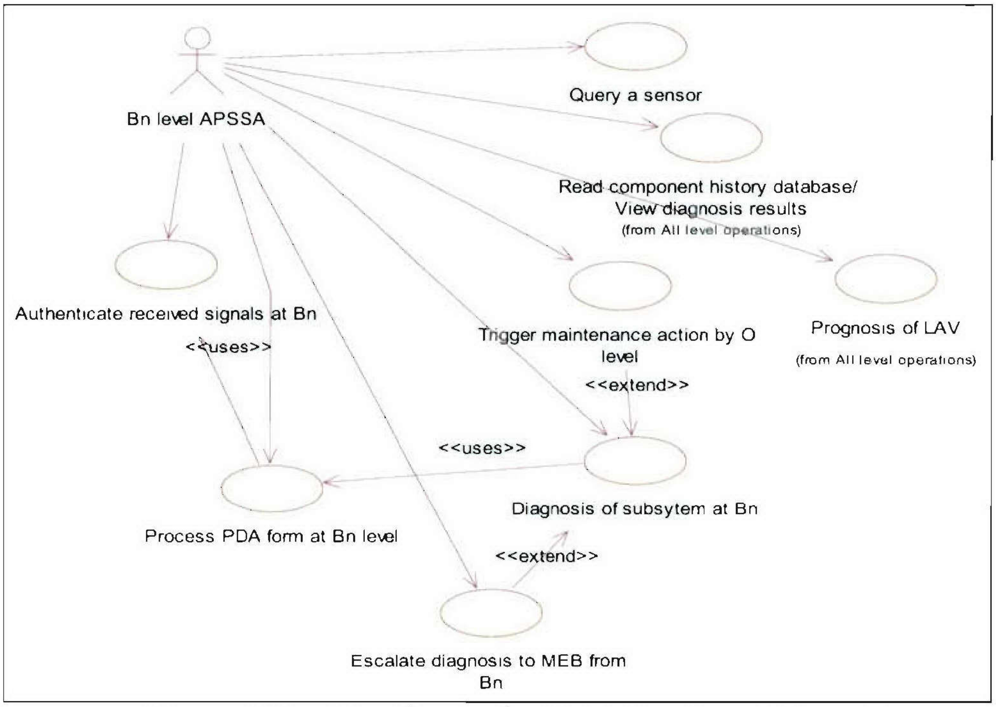

Figure 3.8 Use Cases for Battalion Level Operations

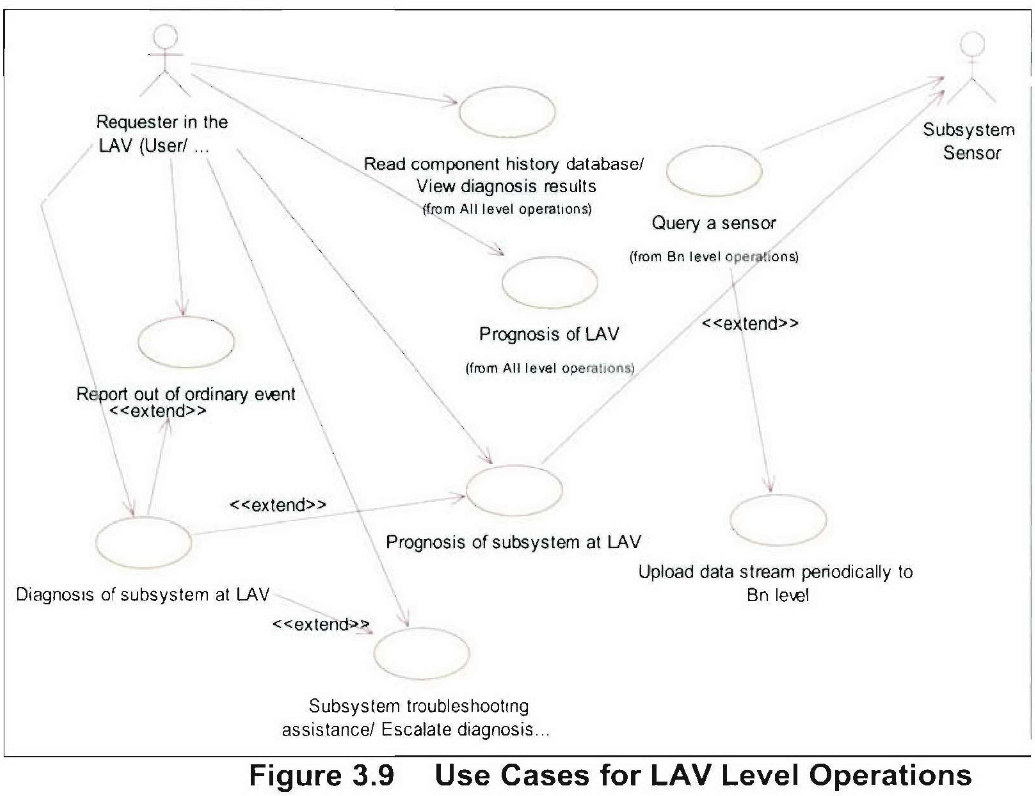

Figure 3.9 Use Cases for LAV Level Operations

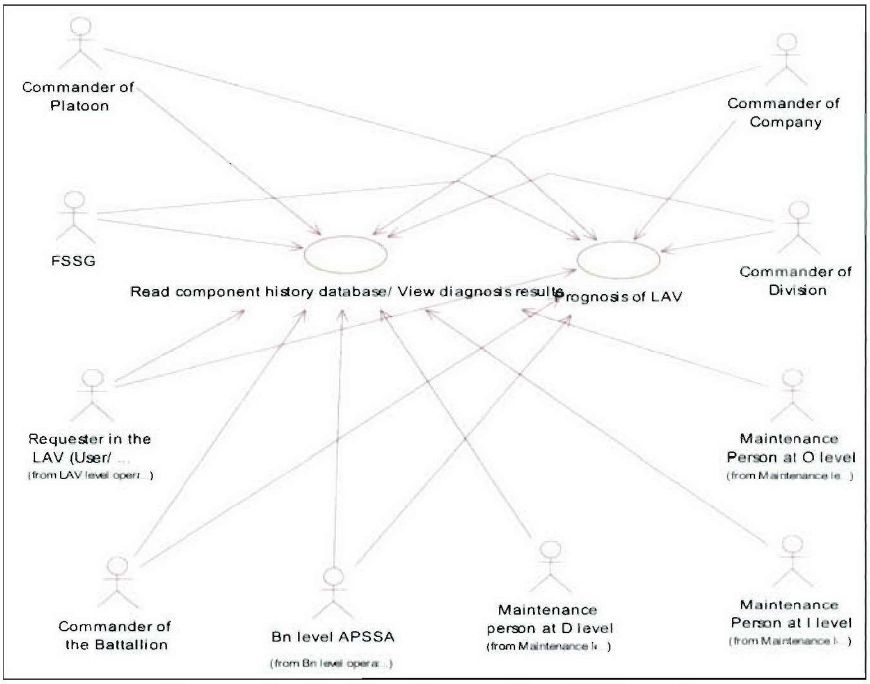

Figure 3.10 Use Cases for All Levels

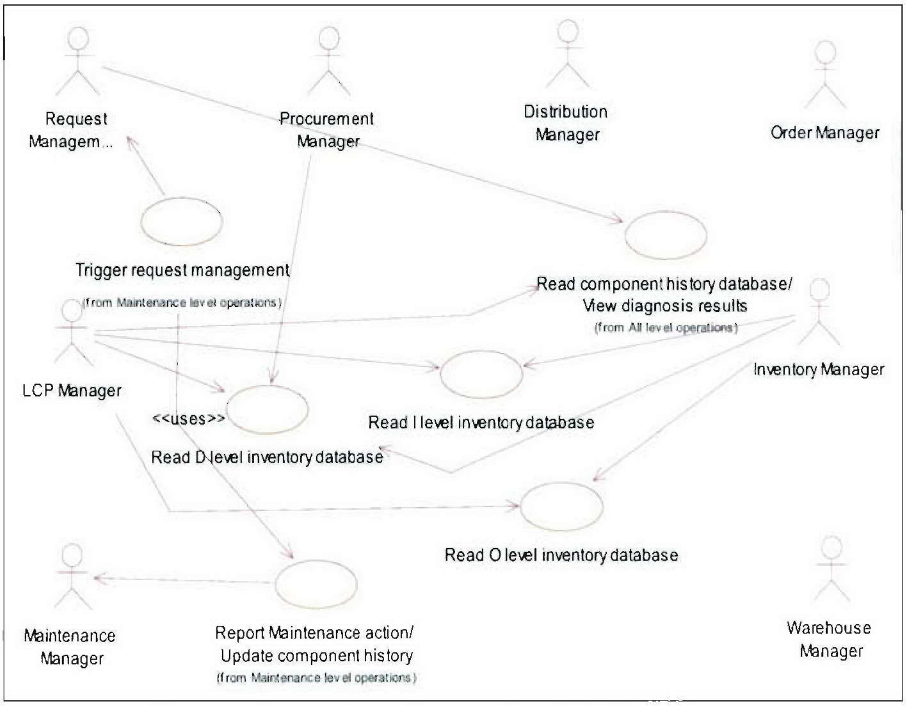

Figure 3.11 Use Cases for OA Functions

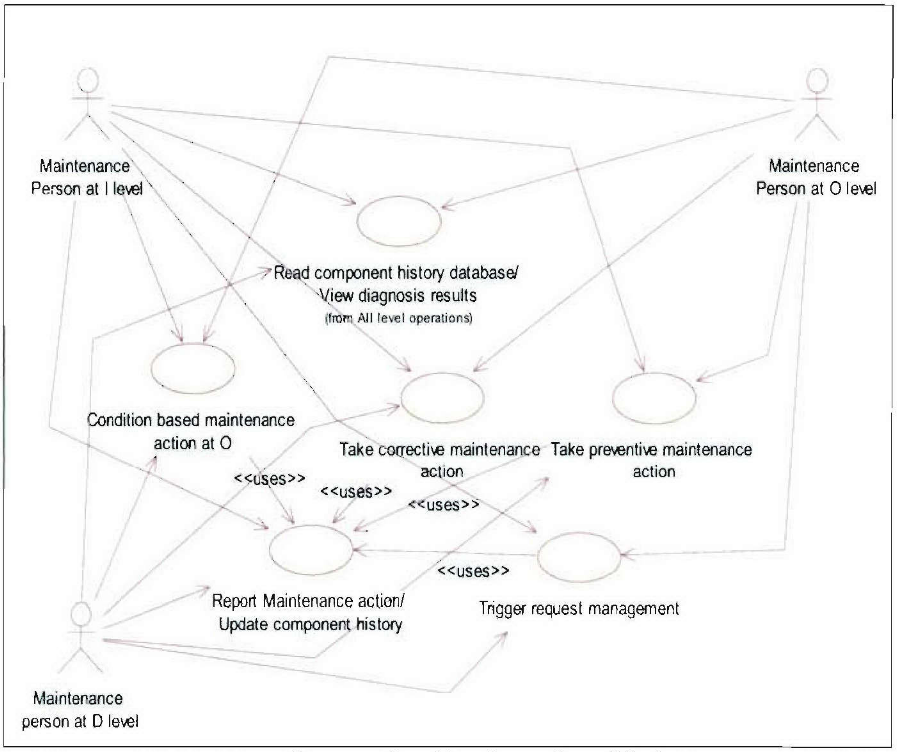

Figure 3.12 Use Cases for Performing Maintenance in Theatre

3.5 Next Steps: Exploiting Use Case Documentation for IDGE Tasks

The use cases were documented by extending the standard format suggested for documenting use cases (see, for example, www.rational.com). The format adopted for this project reflected the nature of tasks that were undertaken by the research team.

Figure 3.13 below shows the format adopted along with expected uses of the documentation for meeting the objectives of this project.

Use Case: Name of the use case
Precondition: What must have taken place prior to executing this use case
Actors: The actor(s) responsible for and benefiting from this use case
Goal: The goal of the use case
Flow of events: Narrative as numbered set of steps
Alternative Flows: Alternative actions, if any, at different steps
Related Use-Cases: Any use cases related to this use case
Frequency of usage: Frequency of use case to be obtained from users
Level of operation: Level in the architecture where the use case will be performed
Data Used: Data that will be necessary to perform the use case
Data Generated: Data that will be generated by the use case
Algorithms used: Algorithms that may be necessary to generate data for the use case
Decision support tools: Software tools that may be necessary to support execution

Figure 3.13 Format Adopted for Documenting Use Cases

Appendix 3.2 shows a total of 20 use cases that were documented using the above format. The documentation shows some information that will be necessary from the users for further analysis of the documentation towards satisfying the project goals.

Specifically, the following represent next steps that can further exploit information available in the use case documentation.

First, three elements - *Frequency of usage* (to be obtained from users), *Data Used* (Data that will be necessary to perform the use case), and *Data Generated* (Data that will be generated by the use case) can be used to clarify the data implications for IDGE. For instance, consider a use case, which is triggered, on average, once every 15 minutes (i.e. 96 times a day) for each of the deployed vehicles (say, 20 vehicles), and each time it is invoked, it generates a data stream of 300kb. This can be used to ascertain the total data that needs to be uploaded.

Second, the element - *Algorithms used* (Algorithms necessary to generate data for the use case) can be identified and mapped against the data mining or CBM techniques available in a bottom-up fashion. This is where the top-down approach exemplified by the use case approach can connect with the bottom-up approach captured by the data mining techniques reported elsewhere as part of this project.

Third, the element - *Decision support tools* (Software tools that may be necessary to support execution) can be identified based on indications by the potential users and knowledge of the marketplace. This can be a useful input to assessing viability of the overall project and for understanding lifecycle costing.

It is expected that the use cases themselves will be refined considerably during the process of accomplishing the above tasks to map against work done in the other directions such as the quadrant model, the FMECA results and degrader results.

Table 3.3 below summarizes these steps.

Table 3.3 Next Steps: Using the Use Cases

Application	Description	Anticipated Results	Tasks
Deriving Profiles of Usage Frequencies and Data Implications for the Scenarios of Use	Obtaining profiles of usage frequencies and converting these to understand data transmission and timeliness rates	Computations of expected data storage and transmission across different levels or the architecture	Task 2.3 What data is required? How the data will be generated/ stored/used? Task 3.1 Determine quantity/ quality timeliness of information to used at different levels
Mapping Algorithms to Scenarios of Use	Understanding the data mining and data fusion algorithms needed for accomplishing the scenarios	Mapping of algorithms to scenarios of use along with identification of possible prognostics at different levels	Task 4.1 Identify data support functions for multi-sensor prognostics integration
Identifying Decision Support Tools and Techniques for Scenarios of Use	Determining tools and techniques appropriate for use at different levels of the architecture where the scenarios of use will take place	Identification techniques such as Automated Reasoning, Cognitive Aids, and tools such as different software packages that may be used during implementation	Task 3.2 Review candidate decision tool technologies and recommend which are most suitable for implementation Task 4.2 Recommend candidate web based technologies for multi-sensor prognostic integration

4 Data Mining concepts and details

4.1 Quadrant Model Review

The quadrant model is a classification tool used to categorize the elements along two distinctly different attributes. Relevant to this study, the attributes considered are the mission value and risk/uniqueness. The main computation performed in this model is the quantification of risk and mission value associated with the different components. In the generic quadrant model, the X-axis represents the mission value of a particular component and the Y-axis represents the risk/uniqueness associated with the components. The value from left to right on the X-axis and bottom to up on the Y-axis increases from low to high.
The quadrant model has two 'dividers' that partition the X -Y plane into four distinct quadrants. They are categorized as "Routine, Leveraged, Bottleneck and Critical". Each of the quadrants represents components with distinct levels of risk and mission value. The dividers can be adjusted to change the fraction of components falling into the four categories. Figure 4.1 shows the quadrant model with a sample of the attributes that ascertain the belonging of the components to the respective quadrants.

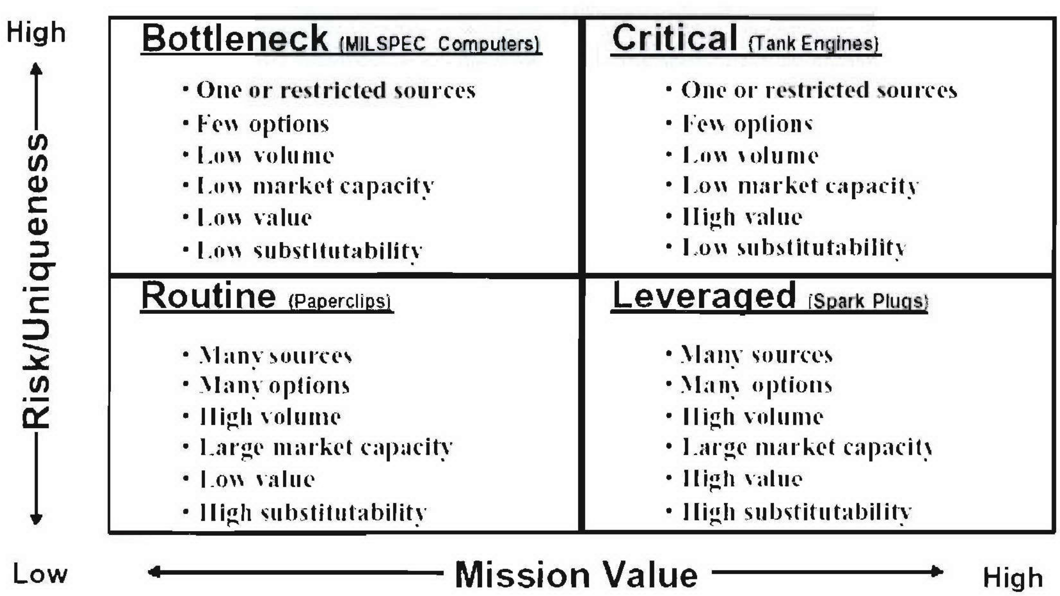

Figure 4.1: Quadrant model showing the attributes & a sample of the various criteria that determine the belonging of each component to the respective quadrants.

With the above concept, specific business rules can be applied for each category to assist in decision making at various levels. In addition, this will help in identifying critical components in the LAV for which Condition Based Maintenance (CBM) can be enforced for diagnosis and prognosis.

The quadrant model assists in decision making. Apart from the quadrant model, various techniques are available for analysis. One such technique considered is" Data mining". Theoretical details of the various Data mining techniques are detailed in the Appendix (7.3). Combining data mining techniques with the quadrant model can improve the granularity of classification of SECREPS.

4.2 Decision Support Systems with Data Mining

In this study, Data mining techniques are needed to support maintenance related decisions that are made at different levels (Strategic, Organization and Tactical) within the USMC. In the quadrant model all the parts that are classified as critical are treated according to the same business rules. There is not much scope for prioritizing the requirements of components within each category of the quadrant model. To achieve greater granularity the use of other data mining techniques are suggested.

The primary decision considered here is that of prioritizing the procurement of components within a fixed budget. The input data considered are similar to those used for the quadrant model analysis (provided by the sponsors). Data elements used were from the FEDLOG, LDR, Supply chain management center, in combination with some of the simulation results.

Though the decision considered here is at the strategic level, similar techniques can be considered for the organizational and tactical levels. At the strategic level the main objective is to limit the costs incurred as part of maintenance procurement, while at the tactical level the emphasis would be on the availability of the required components. The decisions made at the strategic level would be based on historical (long term) data while the tactical level decisions would be made in near real time. It is important that the decision support system developed is aligned along the three different levels to improve operational efficiency. The next sections give details of the use of specific data mining techniques that can be used to supplement the quadrant model analysis. Figure 4.2 shows the overview of the processing element for data mining.

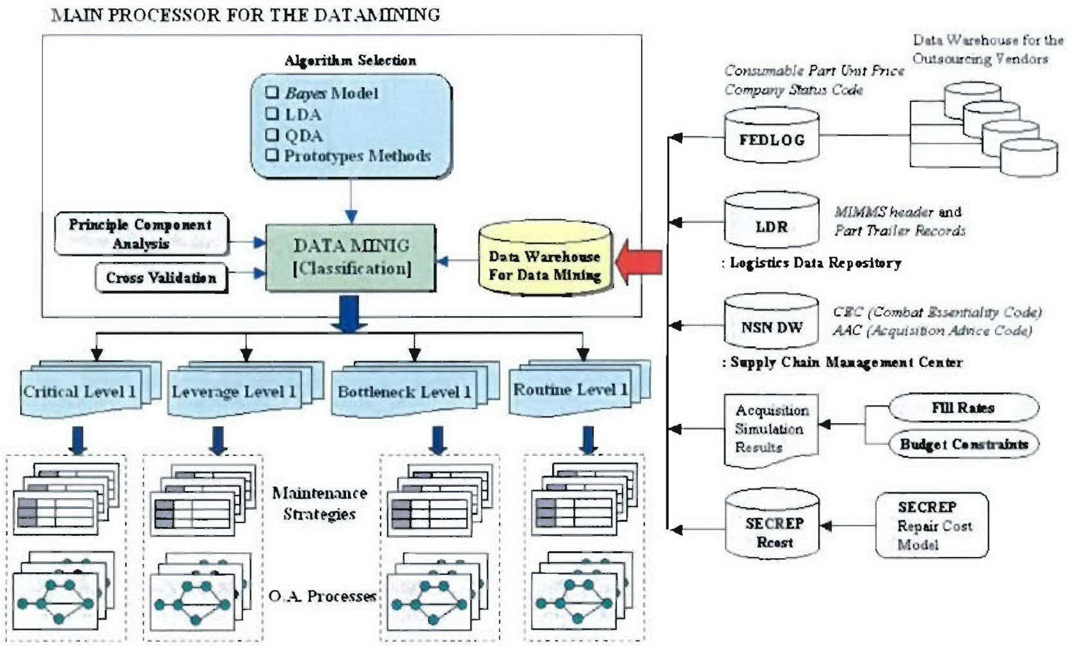

Figure 4.2: Processing elements for Data Mining

4.3 Implementation of Data Mining Techniques

A brief example of applying data mining techniques as a decision support tool in the IDGE architecture is detailed below. Real implementation is conducted based on the domain knowledge of Quadrant model and the given sample dataset, E0947 (LAV-25) SECREP. Classification (supervised learning) algorithms, linear regression indicator matrix, linear discriminant analysis, and quadrant discriminant analysis are applied to build the predictor engine as shown in Figure 4.3. For evaluating and validating the model, cross validation and principal component analysis were conducted.

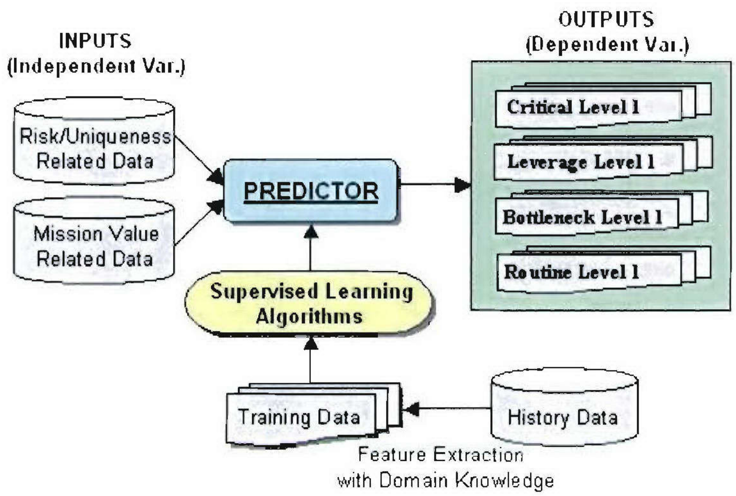

Figure 4.3: Implementation of Data Mining

4.3.1 Implementation of the Classification Algorithm using MATLAB

▪ Program Architecture

Algorithms and techniques used in this data mining study are developed using the MATLAB 6.5. Following show the role of each module included in the program as shown in Figure 4.4.

- LISQ.m reads the original sample data (E0947 SECREPS)
- LSIQ.m calls CV_NORM.m to divide the original data into two sets, training and test, according to the cross-validation method. The predictors (attribute variables) are also normalized in CV_NORM.m according to the range of those in training set.
- PCA.m is called by LISQ.m to do the principal component analysis of training set. It transforms both the predictors in training and test sets into new predictors.
- LISQ.m selects the new predictors according to the number of variable reduction.
- LRI.m, LDA.m, QDA.m are called to classify the given data and provide the performance measures for a single experiment.
- LISQ.m takes the average of *K* experiments from *K*-fold cross-validation.
- LISQ.m summarizes the results (shown in Figures 4.6 and 4.7).

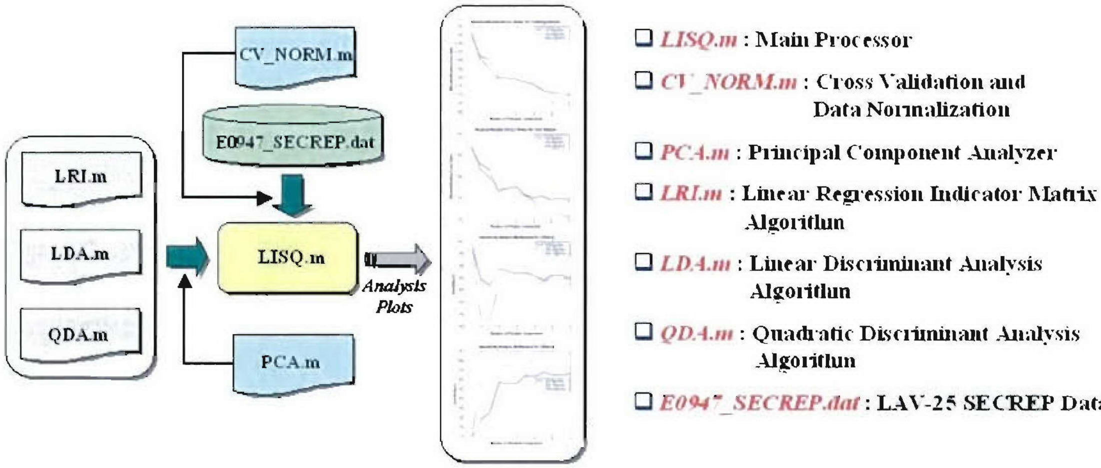

Figure 4.4: Program Architecture

4.3.2 Validation and Evaluation of Data Mining Techniques

To validate and evaluate the data mining techniques, the actual class and predicted class for each item (or NSN) in training dataset and test dataset were compared.

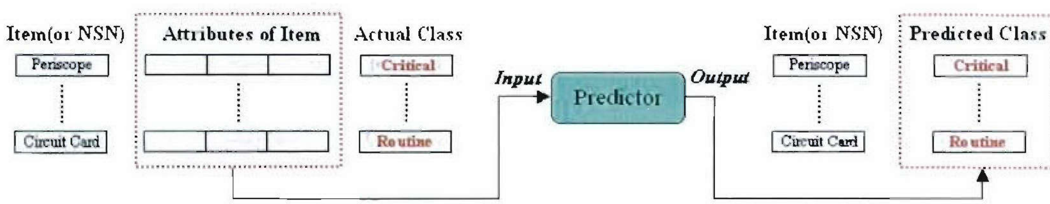

Figure 4.5: Predict Class using SECREPS attributes

4.3.3 Misclassification Error rate of Classification Algorithms with Principal Component Analysis

In addition to the above, misclassification error rates for training dataset and test dataset were analyzed for each applied classification algorithms as shown in Figure 4.6.

$$\begin{aligned}&\textit{Misclassification Error Rate for Training Dataset}\\&=\frac{\textit{Number of mismatched class data (item) in training dataset}}{\textit{total number of data (item) in training dataset}}\end{aligned}$$

where, Mismatched class data means actual class for the data (item) is different from the predicted class

$$\textit{Misclassification Error Rate for Test Dataset} = \frac{\textit{Number of mismatched class data (item) in test dataset}}{\textit{total number of data (item) in test dataset}}$$

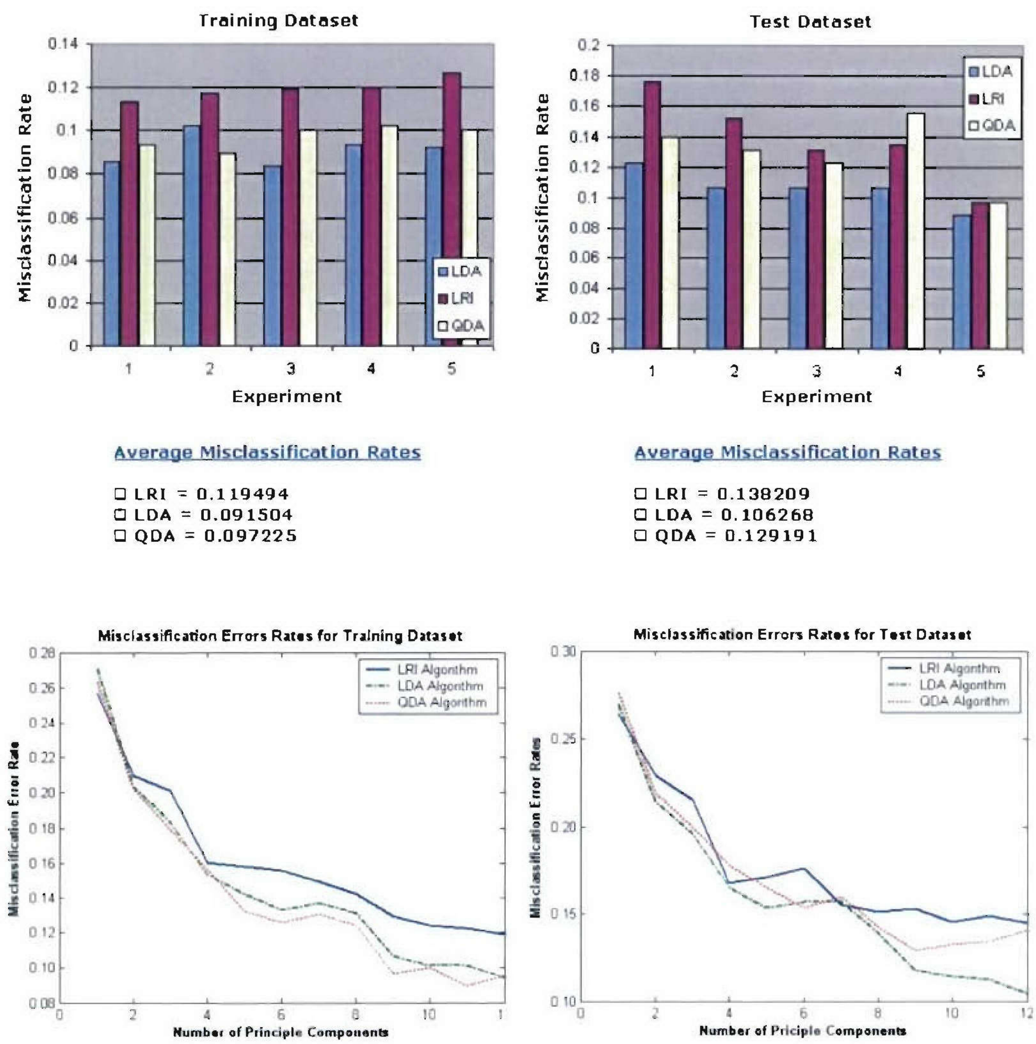

Figure 4.6: Misclassification Error rate of Classification Algorithms with Principle Component Analysis

The above figure shows that the misclassification error rates in training and test dataset decrease as the number of principle components increases. This is an obvious trend. By adding predictors (more principle components), i.e. by increasing the complexity of the boundary, it is always easier to classify each set in samples when their classifications are known.

4.3.4 Sensitivity and Specificity Analysis of Classification Algorithms with Principle Component Analysis

As another effective method to validate and evaluate the model, sensitivity and specificity analysis is conducted with dimension reduction analysis, principle component analysis.

Sensitivity: Probability of predicting a specified class (ex. Bottleneck) given that the true state is specified as the class itself.

TYPE I ERROR (%) = 100 – *Sensitivity*

Specificity: Probability of predicting other classes (ex. Critical, Leverage, and Routine) given that the true state is the other classes themselves.

TYPE II ERROR (%) = 100 – *Specificity*

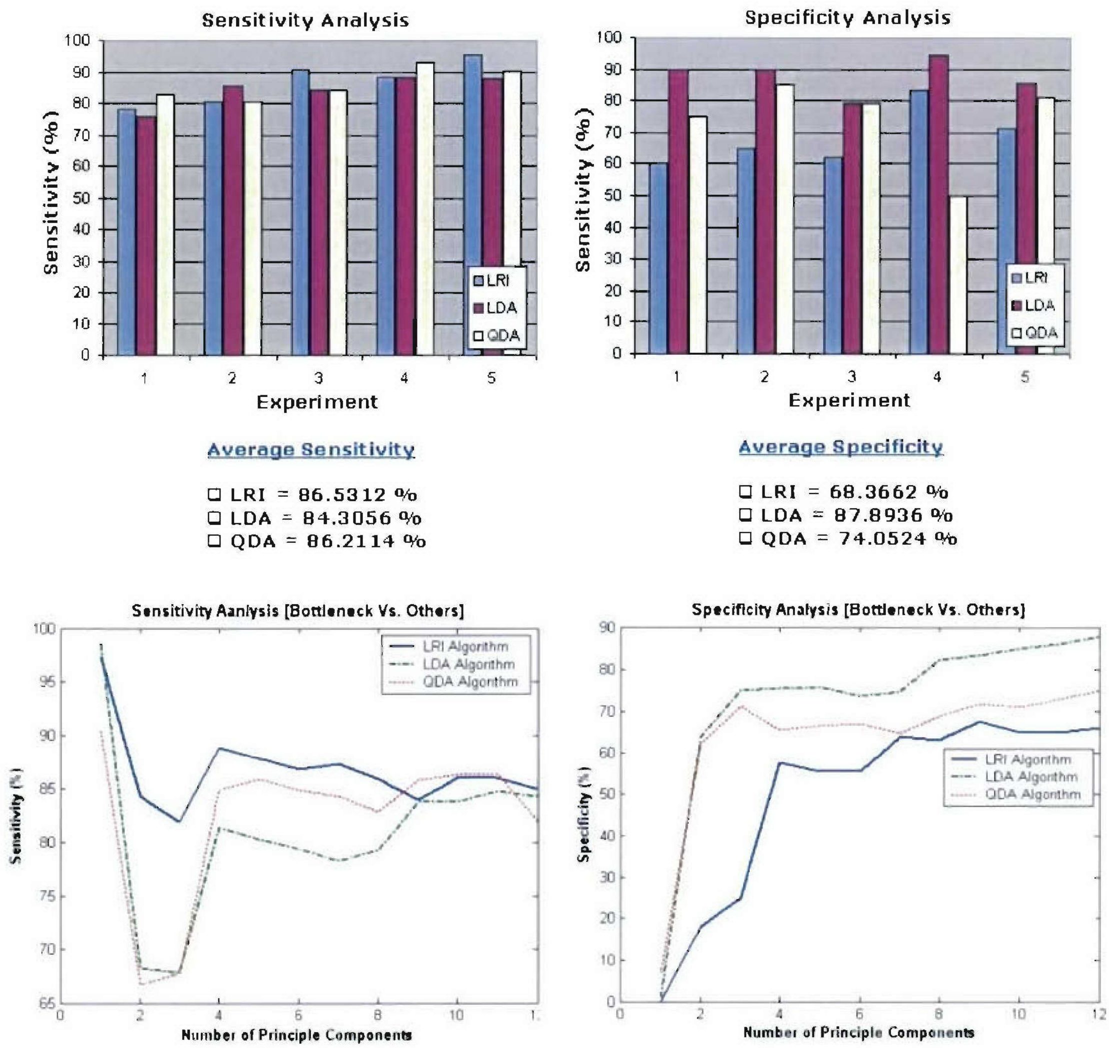

Figure 4.7: Sensitivity and Specificity Analysis of Classification Algorithms with Principle Component Analysis

The above figures give a close look to the misclassification errors for test set. The error can be categorized into two types, and the misclassification errors are thus the weighted average of Type I and Type II errors.

These figures show that Type I and Type II errors can be reduced through variable (dimension) reduction, for Linear Regression Indicator matrix (LRI), Linear Discriminant Analysis (LDA), and Quadratic Discriminant Analysis (QDA).

5 Sensor Fusion and Fault Diagnosis

Multisensor data fusion provides the opportunity to significantly improve the knowledge of the state of USMC resources (platforms, weapon systems, etc.). The use of a broad spectrum of sensors should improve system accuracy, decrease uncertainty, and make these systems more robust to changes in the targets and environmental conditions. A key challenge becomes how to fuse these data to achieve inferences that cannot be achieved using a single sensor or source. Data Fusion systems seek to combine information from multiple sensors and sources to achieve improved inferences than those achieved from a single sensor or source. This section of the report describes the concept of multisensor data fusion, assessment of the state of technology and application of data fusion to condition based monitoring of systems and platforms. Examples of these applications to rotorcraft and land vehicles are also provided. A brief summary is also provided of application of information fusion for: (1) monitoring the condition of individual light armored vehicles (LAV) and (2) monitoring the location and health of several LAVs in a networked, enterprise setting.

The methods and techniques described in the fault diagnosis examples are not limited to air vehicles. They can be used to a variety of mechanical equipment in military and industrial settings. In fact, systems employing such techniques are presently being tested at by the US Navy and US Army for their rotorcraft applications. Also, several industrial systems for fault diagnosis are becoming available. The importance of presenting the appropriate information to the user is now being recognized in the implementation of diagnostic/prognostic systems.

When conducting the top degrader study for the LAV, data from all of the LAV variants was included. This is one of the reasons why the degrader study focused on the drive train of the vehicles because it is a common system across all of the variants. The process used in the top degrader study utilized the MIMMS data, included only data for the LAV. As there are not many common shared components between the LAV and other Marine Corps ground platforms (except for the U.S. Army Stryker Vehicle), the specific MIMMS data used may not be very transferable to other ground vehicle. However, if MIMMS data from a specific ground platform were available, the same systematic analysis used for the degrader study could be conducted on that data set as well. Moreover, the FMECA process itself is applicable to any system under consideration.

A goal of this study is to establish templates that can apply to any piece of ground equipment with a standard means to deploy diagnostics/prognostics, track, evaluate, anticipate failure, activate the supply/maintenance system to request, order and repair the item based upon varying time constraint scenarios. Indeed, data fusion assists in this objective greatly due to its ability to abstract the data into information to be utilized at higher levels of the system hierarchy. Data fusion is applicable at all levels of the system hierarchy. At the lower levels its goal is to bring together diverse data sources and extract key information that is indicative of the equipment condition. At the intermediate levels, its goal is to integrate diverse information sources to evaluate the

system behavior and assess its ability to handle its mission. In addition, at this level actions for maintenance and mission re-planning could be generated. At the higher levels, the goal is to provide contextual, actionable information to various users in the networked enterprise. The examples of systems provided in this review present some demonstrations at various levels. However, not all the previous work has been applied to ground vehicles. Yet, most of the methodology and many techniques can be rapidly applied to ground vehicles applications.

Summary of Accomplishments

During the initial study, the following have been accomplished:

- Reviewed existing health and usage monitoring systems (HUMS) for military and commercial applications;
- Conducted a survey of data fusion technology
- Surveyed commercial off the shelf (COTS) software for data fusion applications
- Developed a concept and architecture for condition monitoring of systems
- Reviewed benefits of data fusion for improved situation assessment in vehicle monitoring applications
- Performed an initial assessment of the applicability of data fusion for USMC monitoring of platforms and weapons systems.
- Assessed the application of data fusion to LAV health and situation monitoring
- Assessed the application of data fusion for monitoring multiple LAVs in a networked, enterprise setting.

Next Steps

Near term activities for the second part of this task include the following:

- Develop a system level concept for intelligent preparation of the logistics battle-space using data fusion concepts
- Review data elements and OA architecture implications for data fusion
- Refine the data fusion concepts for USMC applications at the vehicle level
- Apply FMECA and Use Cases methods into data fusion implementation for the vehicle
- Demonstrate prototype algorithms for data fusion at the signal and report level.

5.1 Concept and Model of Data Fusion

The extensive legacy of department of defense applications such as automated target recognition, situation assessment and threat assessment provides an opportunity for development of sophisticated monitoring systems. In this section the taxonomy and model for data fusion is presented.

New sensing technology provides the opportunity for distributed sensing of the environment using satellites, aircraft, underwater vehicles, mobile robotic devices, and other platforms. Sensed data may include seismic, acoustic, radio frequency, infrared, visible, and environmental sensors to measure a wide cross-section of the environment. Special sensors may be developed to monitor particular chemical or biological effects. Moreover, rapid advances in microprocessors, advanced signal and image-processing algorithms, and improved communications provides the capability for *smart* distributed sensing. Data Fusion systems seek to combine information from multiple sensors and sources to achieve improved inferences than those achieved from a single sensor or source. Applications of data fusion related to the Department of Defense (DoD) span a number of areas including automatic target recognition (ATR), identification-friend-foe-neutral (IFFN), smart weapons, battlefield surveillance systems, threat warning systems (TWS), and systems to support precision guided weapons. Waltz and Llinas [91], Hall [51], and Hall and Llinas [44] provide a general introduction to multisensor data fusion. Additional information can be obtained from the texts by Blackman [11], Antony [2], and Hall [49]. Data fusion systems typically use a variety of algorithms and techniques to transform the sensor data (e.g., radar returns, and infrared spectra) to detect, locate, characterize, and identify entities such as aircraft and ground-based vehicles. These techniques include signal and image processing, statistical estimation, pattern recognition, and many others (see Hall and Linn [41]). In addition, the fusion systems may use automated reasoning techniques to understand the context in which the entities are observed (i.e., situation assessment) and to understand the intent and possible threat posed by the observed entities (i.e., threat assessment).

Over the past two decades, an enormous amount of DoD funding has been applied to the problem of data fusion systems, and a large number of prototype systems have been implemented (Hall, Linn, and Llinas [50]). The data fusion community has developed a data fusion process model [62], a data fusion lexicon [94], and engineering guidelines for system development [83]. While a significant amount of progress has been made (Hall and Llinas [43], [44]), much work remains to be done. Hall and Garga [38], for example, identified a number of pitfalls or problem areas in implementing data fusion systems. Hall and Llinas [45]**Error! Reference source not found.** described some shortcomings in the use of data fusion systems to support individual soldiers, and M. J. Hall, S. A. Hall and Tate [53] discuss issues related to the effectiveness of human-computer interfaces for data fusion systems. Next, the Data Fusion process model developed by the Joint Directors of Laboratories Data Fusion Working Group will be reviewed.

5.2 JDL Model for Data Fusion

A brief summary of the Joint Directors of Laboratories (JDL) data fusion process model is provided next [62], [51], [44]. A top-level view of the model is illustrated in Figure 5.1, and a summary of the processes is shown in Table 5.1. This model is commonly used in the data fusion community to assist communications concerning data fusion algorithms, systems, and research issues. It will be used here for the same purpose.

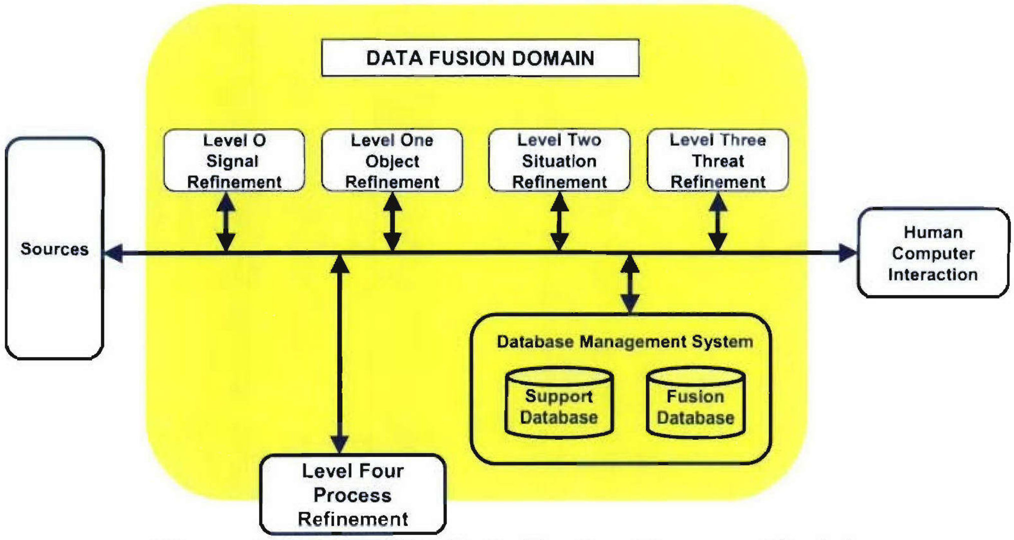

Figure 5.1: The JDL Data Fusion Process Model.

The JDL Data Fusion Working Group was established in 1986 to assist in coordinating DoD activities in data fusion, and to improve communications among different DoD research and development groups. Led by Frank White (NOSC), the JDL working group performed a number of activities including; (1) development of a data fusion process model9, (2) creation of a lexicon for data fusion [94], (3) development of engineering guidelines for building data fusion systems [83], and (4) organization and sponsorship of the Tri-service Data Fusion Conference from 1987 to 1992. The JDL Data Fusion Working Group has continued to support community efforts in data fusion, leading to the annual National Symposium on Sensor Data Fusion and the initiation of a Fusion Information Analysis Center (FUSIAC16).

Table 5.1: Summary of JDL Processes and Functions

Process components	Process Description	Functions
Sources of information	Local and remote sensors accessible to the data fusion system; information from reference systems and human inputs	Local and distributed sensors; external data sources; human inputs
Human Computer Interface (HCI)	Provides an interface to allow a human to interact with the fusion system	Graphical displays; natural language processing
Source Preprocessing	Processing of individual sensor data to extract information, improve signal to noise, and prepare the data for subsequent fusion processing.	Signal and image processing; canonical transformations; feature extraction and data modeling
Level 1 Processing: Object Refinement	Association, correlation, and combination of information to detect, characterize, locate, track, and identify objects (e.g., tanks, aircraft, and emitters).	Data alignment; correlation; position, kinematics, attribute estimation; object identity estimation;
Level 2 Processing:	Development of a description of the	Object aggregation;

Situation Refinement	current relationships among objects and events in the context of their environment.	event and activity interpretation; context-based reasoning
Level 3 Processing: Threat Refinement	Projection of the current situation into the future to draw inferences about enemy threats, friendly and enemy vulnerabilities, and opportunities for operations.	Aggregate force estimation; intent prediction; multi-perspective analysis; temporal projections
Level 4 Processing: Process Refinement	A *meta-process* that seeks to optimize the on-going data fusion process (e.g., to improve accuracy of inferences, utilization of communication and computer resources)	Performance evaluation; process control; source requirement determination; mission management
Data Management	Provide access to, and management of, dynamic data fusion data including; sensor data, target state vectors, environmental information, doctrine, physical models, etc.	Data storage and retrieval; data mining; archiving; compression; relational queries and updates

The JDL model is a two layer hierarchical model that identifies fusion processes, processing functions and processing techniques to accomplish the functions. The model was intended for communications among data fusion researchers and implementation engineers, rather than a prescription for implementing a fusion system or an exhaustive enumeration of fusion functions and techniques. A technology assessment of data fusion and details of some updates to the JDL data fusion model are given in the Appendix 7.4 on Sensor Fusion and Fault Diagnosis.

5.3 Pitfalls in Data Fusion

The previous part of this chapter and its accompanying appendix has provided a broad overview of the state of data fusion technology and identification of potential research issues. A practitioner might well ask the question; so what do I do tomorrow to implement a system? What are some problems and challenges need to be addressed? It is well beyond the scope of this chapter to provide a detailed prescription for the implementation of data fusion systems. However, there are several areas worth noting. First, Bowman and Steinberg [83] provide an overview of the general systems engineering approach for implementation of data fusion systems. Engineering guidelines for selection of correlation algorithms are described by Llinas et al [69]. Several texts, such as those of Hall [51] and Waltz and Llinas [91] provide detailed information on data fusion algorithms. R. Antony [2] describes issues in data base management systems, and texts are available on specific applications to target tracking (e.g., Blackman [11]) and signal processing techniques [88].

Hall and Garga [38] have discussed the problem of implementing data fusion systems and identified a number of problems or pitfalls. These include the following dictums.

- There is no substitute for a good sensor – no amount of data fusion can substitute for a single accurate sensor that measures the phenomena that you want to observe.
- Downstream processing cannot make up for errors (or failures) in upstream processing – data fusion processing cannot correct for errors in processing (or lack of pre-processing) of individual sensor data.
- Sensor fusion can result in poor performance if incorrect information about sensor performance is used – A common failure in data fusion is to characterize the sensor performance in an ad hoc or convenient way. Failure to accurately model sensor performance will result in corruption of the fused results.
- There is no such thing as a magic or golden data fusion algorithm – Despite claims to the contrary; there is no perfect algorithm that is optimal under all conditions. Often real applications do not meet the underlying assumptions required by data fusion algorithms (e.g., available prior probabilities or statistically independent sources).
- There will never be enough training data - In general there will never be sufficient training data for pattern recognition algorithms used for automatic target recognition or IFFN. Hence, hybrid methods must be used (e.g., model-based methods, syntax representations, or combinations of methods).
- It is difficult to quantify the value of a data fusion system - A challenge in data fusion systems is to quantify the utility of the system at a mission level. While measure of performance can be obtained for sensors or processing algorithms, measures of mission effectiveness are difficult to define [91].
- Fusion is not a static process – The data fusion process is not static, but rather an iterative dynamic process that seeks to continually refine the estimates about an observed situation or threat environment.

We note that these issues must be addressed for implementation of an effective data fusion system. Next, we discuss how data fusion is valuable in fault diagnosis.

5.4 Application of Data Fusion to Diagnosis

The problem of determining the condition of complex mechanical systems and accurately predicting remaining useful life is a challenging, multidisciplinary problem. Scientific issues in Condition-based maintenance (CBM) range from understanding fundamental failure phenomena in materials to advanced sensing, fusion of multisensor data, automatic pattern recognition, mathematics of complex system evolution, distributed computing and sensing systems, and automated reasoning. The integration of these disciplines to address the CBM problem advances basic knowledge in each of the component scientific disciplines.

The key to effectively implementing CBM is the ability to detect, classify, and predict the evolution of a failure mechanism with sufficient robustness—and at a low enough cost—to use that information as a basis to plan maintenance for mission- or safety-critical systems. "Mission critical" refers to those activities that, if interrupted, would prohibit the

organization from meeting its primary objectives. "Safety critical" functions must remain operational to ensure the safety of humans (e.g., airline passengers). Thus a CBM system must be capable of:

- Detecting the start of a failure evolution
- Classifying the failure evolution
- Predicting remaining useful life with a high degree of certainty
- Recommending a remedial action to the operator
- Taking the indicated action through the control system
- Aiding the technician in making the repair
- Providing feedback for the design process

These activities represent a closed-loop process with several levels of feedback, which differentiates CBM from preventive or time-directed maintenance. In a preventive maintenance system, time between overhaul (TBO) is set at design, based on failure mode effects, criticality analyses (FMECA), and experience with like machines' mortality statistics. The general concept of a CBM system is shown in Figure 5.3.

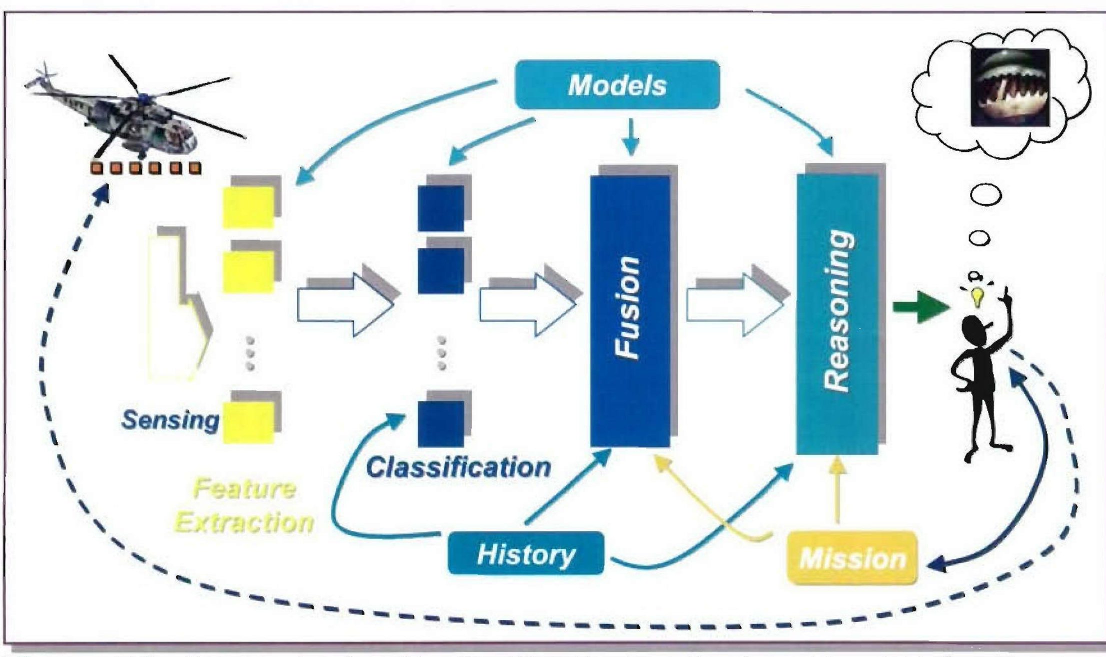

Figure 5.3: Concept of a Health Monitoring System Error! Reference source not found..

The intelligent monitoring system shown in Figure 5.3 has multiple components and functions including; (1) active and passive sensors, (2) signal processing and feature extraction, (3) pattern classification, (4) multi-sensor data fusion, (5) automated reasoning, (6) models, (7) historical data input, (8) mission constraints, and (9) human-in-the-loop decision making. More details about condition-based maintenance approach and implementation issues pertaining to it are given in Appendix (7.4) on Sensor Fusion and Fault Diagnosis.

5.5 Fault Diagnosis Examples

Multisensor data fusion has been recognized as an enabling technology for both military and non-military applications. However, improved diagnosis and increased performance do not result automatically from increased data collection. The data must be contextually filtered to extract information that is relevant to the task at hand. Another key requirement that justifies the use of data fusion is low false alarms. In general, there is a tradeoff between missed detections and false alarms, which is greatly influenced by the mission or operation profile. If a diagnostic system produces excessive false alarms, personnel will likely ignore it, resulting in an unacceptably high number of missed detections. However, presently data fusion is rarely employed in monitoring systems, and when it is used, it is usually an after-thought. In this section, we describe examples of fault diagnosis employing data fusion at the feature and decision levels.

5.5.1 Feature Level Fusion

Vibration monitoring is an integral part of Health and Usage Monitoring Systems (HUMS) for helicopters. Changes in vibration characteristics at different locations in the helicopter can be indicative of various faults. Signal and spectral modeling techniques are used to characterize signals and develop features for detecting various faults in the machinery. Adequate modeling of the signals often requires large model orders, especially due to the presence of intermodulation and other sources of noise. However, for fault classification and localization, it is usually possible to derive a reduced set of features through various types of transformations. Previously, such an approach was demonstrated with the Westland helicopter transmission vibration signal data set, which consists of no-fault and seeded-fault test runs of a CH-46E aft transmission [34]. In this section, the benefits of this methodology for monitoring of helicopter gearboxes are demonstrated using seeded fault helicopter data for an H60 intermediate gearbox [22].

The data used for the evaluations reported herein are from a seeded fault test of an intermediate gearbox (IGB) pinion for an H60 helicopter. The data was acquired under the Helicopter Integrated Diagnostic System (HIDS) Program at the Naval Air Warfare Center Aircraft Division in Patuxent River NAS, Maryland. The test conducted involved fault propagation on an IGB pinion, where a small Electrical Discharge Machine notch was used to initiate a stress riser in the root of a tooth. A crack was then grown from the seeded notch by running the test rig at 100% tail power for a total of 2 million cycles Figure 5.6.

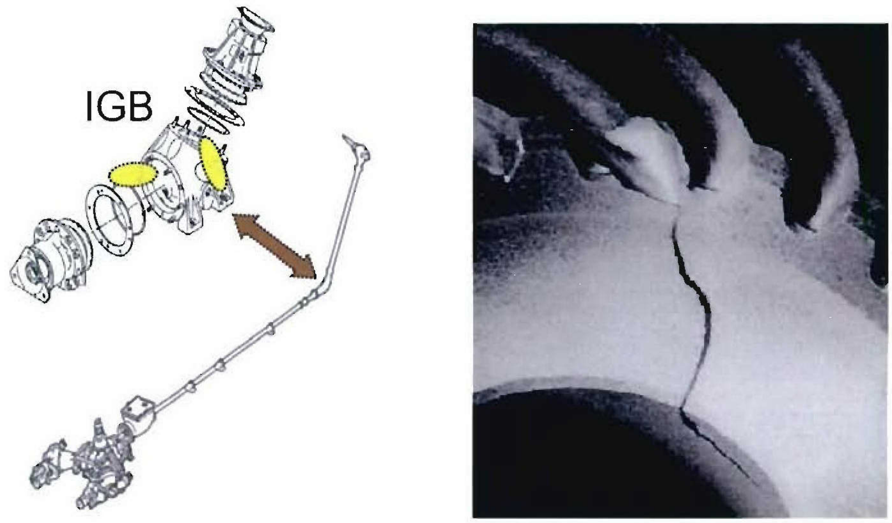

Figure 5.6: Intermediate Gearbox Pinion fault.

Several useful techniques have been developed to extract features from the vibration signature [67]. Generally these features are more stable and well behaved than the raw signature data itself. In addition, the features constitute a reduced data set, because one feature value may represent an entire snapshot of data, thus facilitating additional analysis such as pattern recognition for diagnostics and feature tracking for prognostics. Moreover, the use of feature values instead of raw vibration data will become extremely important as wireless applications, with greater bandwidth restrictions, become more widely used. Figure 5.7 illustrates an example of the processing flow for feature extraction. This process was implemented in a MATLAB-based CBM Toolbox developed at the Penn State ARL.

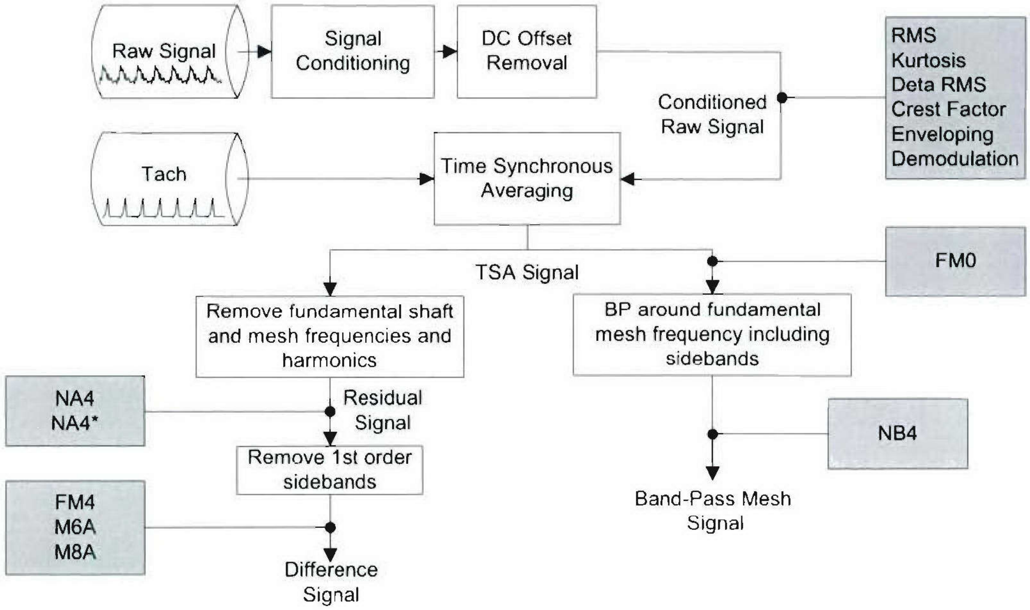

Figure 5.7: Processing flow for vibration signal feature extraction.

Classification techniques for fault identification attempt to map sensor measurements or feature vectors into indicators of distinct fault conditions. Such a mapping must transform the data or feature vectors into *separable* groups of patterns in feature space. That is, feature vectors that represent different fault classes should result in clusters (or groupings), which are widely separated, when represented in feature space. This is not necessarily an easy task and may require the use of feature transformation techniques and feature selection. The underlying assumption for such an undertaking to be successful is that the data from no-fault condition and the various types of fault conditions arise from different distributions. The results of fault severity classification based on feature level fusion are shown in Figure 5.8. Note that despite the variation in feature values, the classification is stable due to the benefit of fusion.

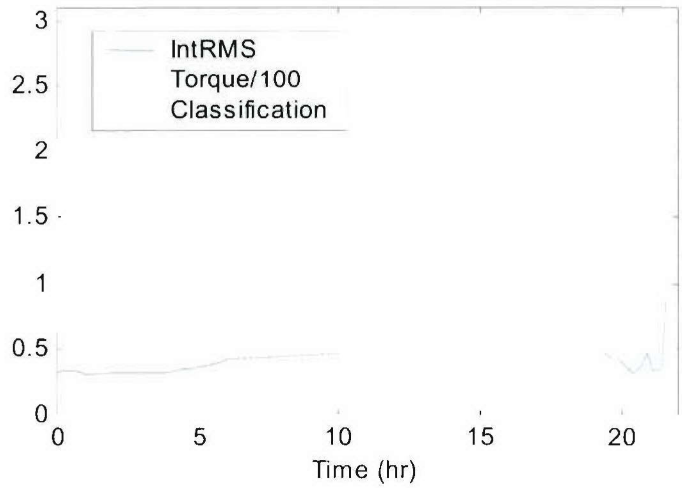

Figure 5.8: Classification results over the duration of the test run.

Previously, benefit of feature level fusion for classification among several fault types was shown using CH-46 aft transmission vibration data. Faults with greatly differing criticality (e.g., shaft cracking and bearing corrosion) are often confused due to similar symptoms (see Figure 5.9). However, using feature level fusion such faults are separated. This enhances the situation awareness and also maintenance effectiveness. In particular, without the feature level fusion the rotorcraft would be flagged for maintenance and this would lead to unnecessary troubleshooting and unnecessary maintenance action. Moreover, the vehicle would be unavailable longer. On the operational side, the benefit of increased awareness is fewer aborted missions [33].

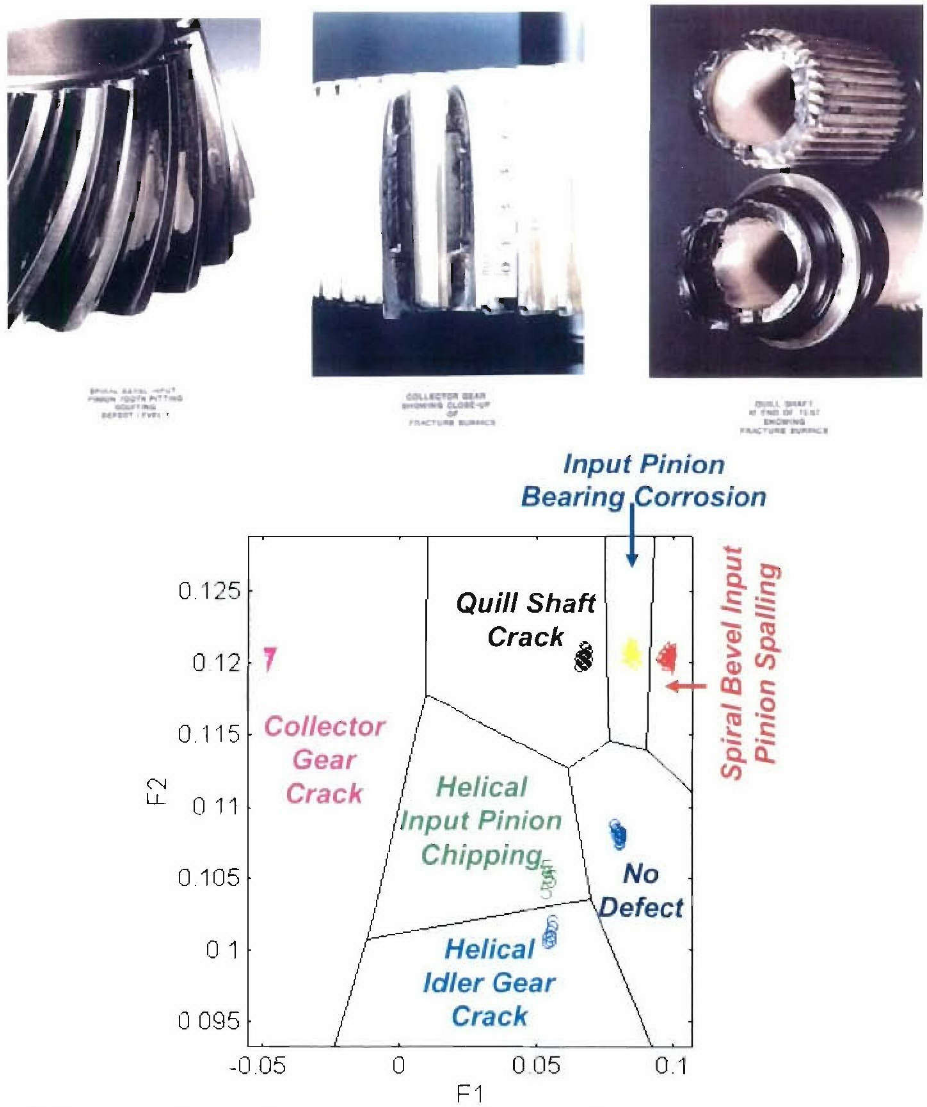

Figure 5.9: Fault Classification using CH-46 aft transmission multi-sensor vibration signal data.

5.5.1.1 Decision Level Fusion

The application of data fusion techniques to condition monitoring of complex systems would appear to provide advantages for accurately characterizing the state of the system. To date, however, only a few attempts have been made to develop such systems. McGonigal [72] compared three techniques (neural networks, fuzzy logic, and rule-based reasoning) for decision level fusion of vibration data for the mechanical diagnostic test bed. The benefit of decision level fusion on estimation of the remaining useful life is shown in Figure 5.10.

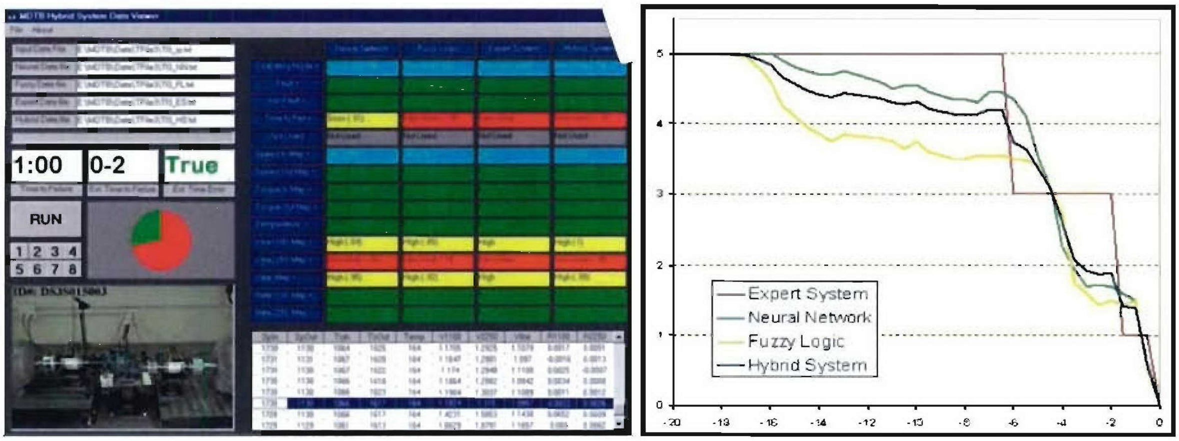

Figure 5.10: Decision level fusion for RUL estimation.

Kozlowski developed a feature-level fusion approach for battery systems that proved to be very robust (see the discussion in Byington and Garga [16]). Erdley [29] tigated several voting schemes for data fusion for the Penn State mechanical diagnostic test bed, and showed the utility of fusion methods (see Figure 5.11). Finally, Garga [35] utilized hybrid-reasoning techniques for feature-level and decision-level fusion.

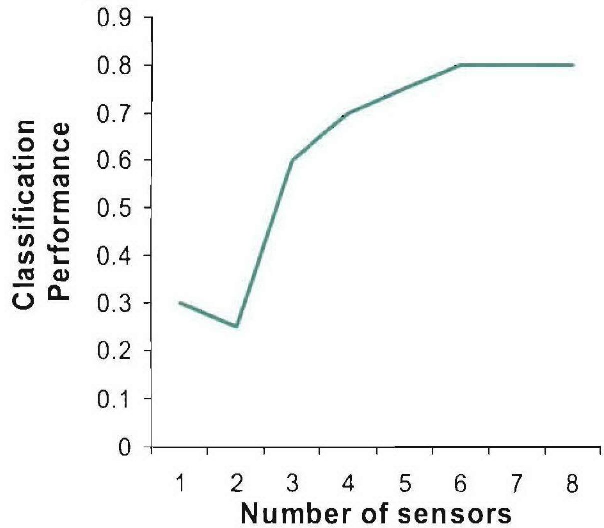

Figure 5.11: Improved fault classification performance with decision level fusion.

The benefit of HUMS information to situation awareness was recently described by Garga et al for a rotorcraft application [33] Figure 5.12 shows the types of information that can be communicated to the aircrew and the maintenance personnel based on the HUMS data. In this development, the procedures and checklists that are used by the aircrew were made available in electronic format. As a result the appropriate procedure and checklist were provided the aircrew based on the specific problem that developed in the scenario being demonstrated.

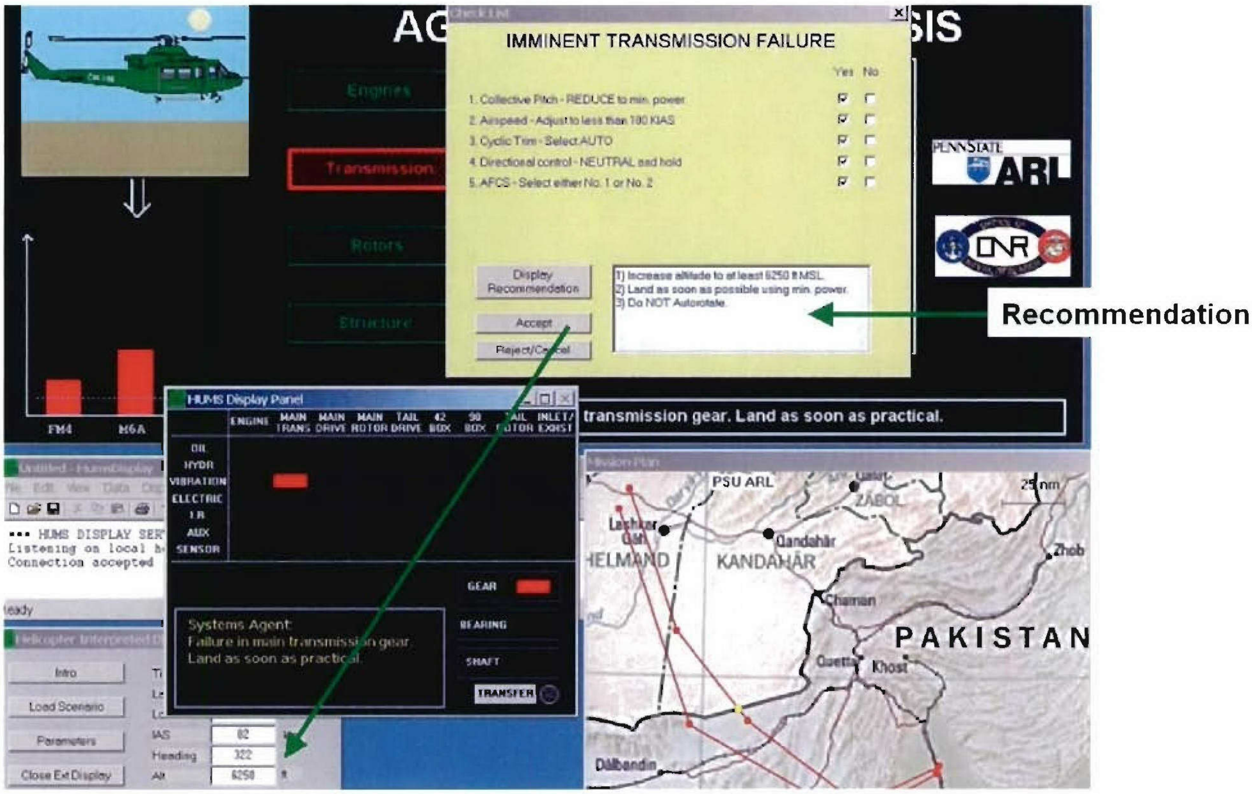

Figure 5.12: Demonstration of HUMS information for increased aircrew awareness.

Various types of knowledge are used in hybrid reasoning and in fault diagnosis. A FMECA and knowledge elicited from the field personnel are typically found to be very useful. Next, a study is described that provides useful information about the top degraders in the LAV.

5.5.1.2 LAV Top Degrader Study

A study **Error! Reference source not found.** was performed to identify the top degraders of the US Marine Corps Light Armored Vehicle at the request of the Program Management office for LAV (see Figure 5.13). The top ten degraders were identified with respect to their effects on availability, reliability and performance. The Penn State Applied Research Laboratory also identified opportunities for the application of vehicle based diagnostics and prognostics that would mitigate the effect of the principle degraders.

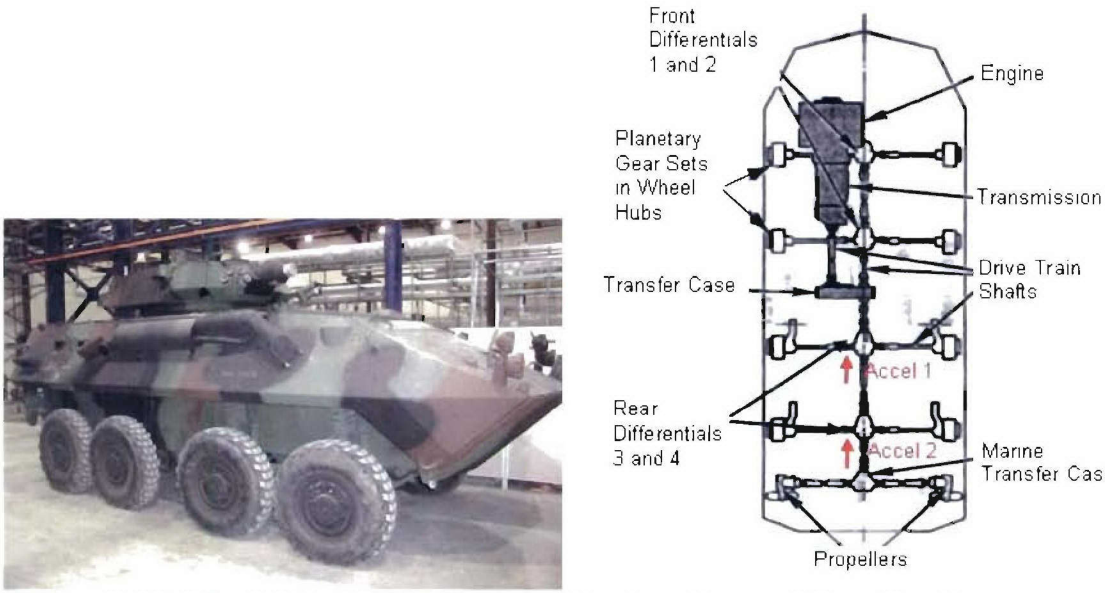

Figure 5.13: The LAV at PSU ARL with the locations of the vibration sensors.

The methodology used to determine the vehicle's top degraders consisted of three parts: analysis of the MIMMS data to evaluate which parts were replaced most often, interviews with vehicle maintainers to assess issues in the field and a failures modes and effects analysis (FMEA) that was developed by Penn State ARL for the vehicle.

The analysis indicated that the top degraders to vehicle mobility are:

1. Differentials
2. Batteries
3. Planetary Gear Set in Wheel Hubs
4. Alternator
5. Transfer case
6. Seals
7. Fuel Pump
8. Vehicle Hydraulic System
9. Diesel Engine
10. Transmission

When a simple tally of the number of replaced parts per year is evaluated, it is a straightforward assessment to rank the top vehicle degrader in terms of mobility, but this assessment is not complete. Many factors must be taken into account, such as ranking the severity of the consequences of failure of each sub-system upon the primary vehicle function of mobility, logistic delay time for obtaining replacement parts and the ease of diagnosing and isolating faults for each sub-system. The combination of these additional factors makes it more difficult to conclude that one system is the clear outstanding top LAV mobility degrader. It is clear that when considering all of the data, three sub-systems stand out equally as the top degraders related to the operation and

maintenance of the LAV. These sub-systems are the differentials, batteries and planetary gear sets in the wheel hubs.

The suggested path forward from the results of this analysis is to apply the appropriate health monitoring technology based on the results of the FMEA to the top two to three vehicle degraders. The technology can then be field tested to validate the benefits from the implementation of asset health monitoring on the LAV.

Analysis Process

The methodology for identifying the vehicle degraders and the technology for vehicle health monitoring involves a combination of three steps: review and compile parts ordered records (MIMMS data), conduct interviews with experienced maintainers of the LAV and perform a modified failure modes and effects analysis (FMEA).

The first step of the process provides a method for identifying the 'realistic' top degraders of vehicle operation and maintenance. This was conducted by analyzing the MIMMS data supplied by PM LAV, which includes the parts ordered records. In order to establish the scope of the analysis, the primary and secondary functions of the vehicle must be defined. The primary function of the vehicle is to transport combat ready Marines and the vehicle crew members to their mission destination over land and through small water obstacles in a safe and timely manner. The LAV also has many secondary functions that are dependant upon the design variant of the vehicle. The eight LAV design variants including vehicle designation, number of vehicles for each designation and description of vehicle function is shown in Table 5.3.

Table 5.3: LAV Design Variants

Designation	Number	Type
LAV-25	408	Personnel Carrier
LAV-AT	95	Anti-Tank
LAV-L	94	Logistics
LAV-C2	50	Command and Control
LAV-M	50	Mortar
LAV-R	45	Maintenance and Recovery
LAV-AD	17	Air Defense
MEWSS	12	Mobile Electronic Warfare Support System

The analysis consisted of determining, which vehicle components are most critical to the primary function of the vehicle as well as which components were replaced most often. Several parts such as nuts and bolts have a high replacement rate but they are not necessarily critical to the mobility of the vehicle. The focus of the analysis was directed at the prime mover, the drive train and the mobility critical subsystems such as the hydraulic, pneumatic and electrical power systems.

The MIMMS data consists of a list of the number of parts ordered each year from 1999 through 2002 as well as the part ordered and part received dates. The number of parts ordered was compiled for each year and the results from all four years were averaged to provide a mean value. In order to estimate the deadline time the vehicles may

encounter due to the time it takes to order and receive parts, the logistic delay time for each component or sub-system was calculated. Using the ordered/received dates a logistic delay value in days was estimated (received date minus ordered date) and the average of these values over the four years was also determined. Since the logistic delay values showed a significant variation, the standard deviation of the values was calculated to show the distribution of the logistic delay. The average of the standard deviations was also determined.

The next step of the analysis process involved conducting interviews with Marine and civilian contractor maintenance personnel to ascertain which components contribute the most to low vehicle reliability and availability. The interviews were focused on gaining perspective about maintainability issues associated with diagnosing and replacing vehicle line replaceable units (LRU). The data gathered from the interviews was compared to the parts ordered data to corroborate the information. The interviews were conducted at three locations including: the Schoolhouse at Aberdeen Proving Grounds, Maryland, the Exercise Support Division and 3rd LAR Bn. at Twenty Nine Palms, California and the 1st LAR Bn. at Camp Pendleton, California. Questionnaires were also sent to PMO-LAV at Albany, Georgia and the 2nd LAR Bn. at Camp Lejeune, North Carolina.

The third step of the process provides a method for analyzing the detailed degradation issues and identifying diagnostic and prognostic technology for each degradation failure mode. The FMEA method is a tool for identifying and evaluating the function failure modes (degraders) of a system as well as how to detect and monitor for each of the failure modes. The process starts by describing the function of each component or sub-system and then listing failure modes that prevent the implementation of that function. The frequency of occurrence or the likelihood that that failure mode will occur is based on the data from the MIMMS data. The consequences of the failure in terms of operational availability of the vehicle and maintenance issues for each component must also be ranked by severity level. The severity levels for each component or sub-system is are based on four factors:

1. Diagnosis and Fault Isolation in the Field
2. Part Availability in the Field
3. Time to Repair in the Field
4. Failure Affect on Mission

The severity ranking is the sum of the four parameters for each component evaluated. The ranking ranges from 0 to 40, where 0 is the least severe consequences and 40 is the most severe consequences.

The symptoms and effects of each failure mode are also listed through the FMEA process. The symptoms are defined as events that can be observed prior to the failure mode occurring or when the failure mode is in early stages of development. The effects are defined as events that are a direct result of the failure mode where effects in 'yellow' are downstream failure modes. The symptoms and effects are essentially a list of

events that provide an indication of the presence of a fault in the system. The component column identifies the component immediately affected by the failure mode. The sensors column lists the instrumentation that would be used to observe or detect the symptom or effect of each failure mode. The sensor component column indicates the component to which the sensor is linked or located. The sensor information is an addition to the standard FMEA format because it provides important information for determining how the indicators of the failure mode should be monitored. Finally, the last column lists the algorithms, techniques and technologies that can be used with each sensor to detect and diagnose the occurrence of each failure mode. The FMEA's will be used as a guide for the architecture development of the vehicle health monitoring system. An example of the FMEA format from the LAV degrader study is shown in Figure 5.14. For further detail see [4].

Function	Functional Failure Mode	Symptoms/Effects	Component	Sensors	Sensor Component	Diagnostics
The battery has the ability to store electrical power to start the vehilce and provide sufficient energy for auxillary electrical systems. The battery must also be able to discharged and recharged	Cell Failure (degraded performance)	Low storage capacity	Battery System	Impedance Sensor	Terminals	Battery Features
		Will not accept charge	Battery System	Impedance Sensor	Terminals	Battery Features
		Vehicle may not start with multiple cell failures	Battery System	Operator	Vehicle	Human Observation
	Terminal Faults (broken or corrosion)	Will not accept charge	Battery System	Impedance Sensor	Terminals	Battery Features
		Vehicle may not start	Battery System	Operator	Vehicle	Human Observation
	Deep Cycle Failure	Low storage capacity	Battery System	Impedance Sensor	Terminals	Battery Features
		Will not accept charge	Battery System	Impedance Sensor	Terminals	Battery Features
		Vehicle may not start with multiple cell failures	Battery System	Operator	Vehicle	Human Observation
	Broken Case	Will not accept charge	Battery System	Impedance Sensor	Terminals	Battery Features
		Vehicle may not start	Battery System	Operator	Vehicle	Human Observation

Figure 5.14: Battery FMEA developed for the LAV Degrader Study

At Penn State ARL, a demonstration was done show how the information collected on several vehicles can be communicated upward for various customers for command and control and logistics management Figure 5.15. Several tabs can be seen at the top of the display: (1) Asset visibility, (2) Status & Performance, (3) Condition & Health, (4) VMS system, (5) Trends, (6) Video, and (7) Connections. The display shows asset identification, position, speed, heading, fuel level, etc. for several vehicles in the area of interest. These are based on the GPS information communicated by the vehicles regularly. Under other tabs information relevant to that category is presented. Thus, the desired information is available in a timely manner and alerts can be communicated without delay. More details can also be accessed by querying the system on the appropriate screen. For example, under Condition & Health tab, one can access indicators that are used for determining vehicle health. Such information is updated in real-time and significantly increases the situation awareness and mission effectiveness.

Figure 5.15: Vehicle and Systems Health Information.

Further details about data fusion and fault diagnosis are given in the Appendix 7.4 on Sensor Fusion and Fault Diagnosis. The references pertaining to this chapter are also given in that appendix .

6 Marine Corps Equipment Readiness Information Tool (MERIT) Review

MERIT is a non transactional web based tool currently in use at the USMC. Its key functions include enabling visualization of the equipment readiness status by using detailed supply and maintenance information. MERIT transforms the maintenance data into relevant information that provides a near real time view of equipment readiness. It presents a comprehensive Marine Corps readiness posture while presenting detailed information about the availability of specific parts. It contains a graphical user interface in combination with a readiness analysis tool. It essentially automates the process of developing detailed readiness maps. Thus it reduces the work load on the analysis experts.

MERIT uses and open source java-based programming technique. The delivery method uses a web browser using java applet running on a server, this is connected to the data source such as Oracle, XML or delimited text. MERIT also uses a combination of filters, labels and search tools either group the data in numerous desired ways or presenting multiple calculations for current and historical USMC readiness data. It also uses different color schemes for representing the data element and thus enables easy visualization.

A critical review of the MERIT system will help the team identify the different maintenance data that the system is currently capturing. It will also help the team review the techniques that are used to store/catalogue the data elements. Such a critical analysis will help the study team augment the type of data captured so as to use them in the proposed transactional system. Further review and analysis of MERIT will be performed by the team in the immediate future. Details of the tasks scheduled in this regard are mentioned in the 'Planned work' section of this document.

7 Appendices

7.1 Appendix 1 - List of Actors

Actor	Description
Commander of Company	Commander of the Company in the field who has read-only access to component history database to determine health status of deployed vehicles and sub-systems. Company is the 2nd from smallest (between Battalion and Division) deployed unit in the field
Commander of Division	Commander of the Division in the field who has read-only access to component history database to determine health status of deployed vehicles and sub-systems. Division is below Platoon and above Company in the hierarchical organization of deployed soldiers. (2nd from the largest)
Commander of Platoon	Commander of the Platoon in the field who has read-only access to component history database to determine health status of deployed vehicles and sub-systems. Platoon is the largest deployed unit in the field.
Commander of the Battalion	Commander of the Battalion in the field who has read-only access to component history database to determine health status of deployed vehicles and sub-systems. Battalion is the smallest (among company, division, battalion and platoon) deployed unit in the field.
Battalion level Active Passive Sensor Signal Analyst (APSSA)	System OR human processing and analysis of the sensor/ PDA signals received from the field. Hub of all activities/ decision making at Battalion level. Interfaced with Diagnostic unit, O level inventory database and component history database.
Requestor in the Vehicle (User/Non-User)	Personnel in the LAV who perform diagnosis of subsystems, reporting of out of ordinary events and day-to-day maintenance operations of the LAV for e.g. mechanic, driver, turret operator etc
Subsystem Sensor	Sensor installed on various subsystems in the LAV that feed a stream of data to the LAV system processor for prognosis purposes.
Maintenance Person at D-Level	Personnel at D level maintenance that perform actual corrective, preventive or condition based maintenance work on the LAV subsystem/ component. D-level is the highest level among the 3 maintenance levels and corresponds roughly to the MEF/ Sea Base organizational level. Also interfaces with Request Management function of OA processes.
Maintenance Person at I-Level	Personnel at I level maintenance that perform actual corrective, preventive or condition based maintenance work on the LAV subsystem/ component. I-level is the middle level among the 3 maintenance levels and corresponds roughly to the MEB organizational level.
Maintenance Person at O-Level	Personnel at O level maintenance that perform actual corrective, preventive or condition based maintenance work on the LAV subsystem/ component. O-level is the lowest level among the 3 maintenance levels and corresponds roughly to the Bn organizational level.
MEB Level Active Passive Sensor Signal Analyst (APSSA)	System OR human processing and analysis of the signals received from the Battalion level. Hub of all activities/ decision making at MEB level. Interfaced with Diagnostic unit, I level inventory database and component history database.

MEF Level Active Passive Sensor Signal Analyst (APSSA)	System OR human processing and analysis of the signals received from the MEB level. Hub of all activities/ decision making at MEF level. Interfaced with Diagnostic unit, D level inventory database and component history database.
Distribution Manager	Manager of DM functions. Responsibilities involve managing and planning the distribution strategy and transportation of inventory
Inventory Manager	Manager of IM functions. Responsibilities include managing the inventory strategies after planning processes are determined.
LCP Manager	Manager of LCP functions. He is located at enterprise level. The duty of LCP manager is planning and designing logistic chain to fulfill customer's demands.
Maintenance Manager	Manager of MM functions. Responsibilities include scheduling and reserving specific resources to support overall fulfillment requirements for maintenance services. In addition, the Maintenance Operations Management function will also adjust schedules and or resources according to feedback from the execution function.
Order Manager	Manager of OM functions including routing, coordinating, tasking, and tracking customer orders through fulfillment. This function works by receiving requests from customers, generating customer orders (based on requests) and initiating the fulfillment of products and services. In addition, OM processes communicate order status to the customer.
Procurement Manager	Manager of PM functions that include making decisions to ensure that the necessary procurement capacity is available to meet demand. This process also serves to coordinate with other logistics capacity management functions to ensure that requirements are understood and that the fulfillment of product needs to customers can be coordinated, measured, evaluated and managed to meet expectations
Request Management Manager	Manager of RM functions including generation and approval of customer demands. Basically, it works by validating customer requirements and generating requests for logistics support (fulfillment of products and services) if required. RM receives requirements from within the customer / supported unit; prioritizes requirements, sources the demand internally or processes the requirement into a request and submits the request to be created into an order.
Warehouse Manager	Manager of WM functions. Includes responsibilities such as planning of packing and shipping items for fulfillment of customer orders or replenishment of inventories at other locations OR receiving items from providers (internal and external), verifying and recording assets received, recording and reporting discrepancies and storing the items for the fulfillment of anticipated customer orders.
Sea Base Level Active Passive Sensor Signal Analyst (APSSA)	System OR human processing and analysis of the signals received from the MEF level. Hub of all activities/ decision making at Sea Base level. Interfaced with Diagnostic unit, D level inventory database and component history database.

7.2 Appendix 2 - Use Case Documentation

Use Case 1: Read component history database/ View diagnosis results

Precondition: The IDGE system (at various levels) is monitoring the health status of a subsystem/ component in the LAV and storing this data in the component history database as well as all the previous diagnosis results and other component level details.

Actors: APSSA at Battalion level, APSSA at MEB level, APSSA at MEF level, APSSA at Sea Base level, Maintenance person at O level, Maintenance person at I level, Maintenance person at D level, LAV requestor (User and Non user), Commander of platoon in field, Commander of division in field, Commander of company in field, Commander of FSSG in field, Commander of Battalion in field

Goal: To allow the above actors involved at various levels to log into the component history database and read a comprehensive history report of the component (or sub system under consideration) including past diagnosis results, component specifications and other details.

Flow of events:

1. The actor/s mentioned above logs into the component history database (at his respective level) to read component history/ view the diagnosis results.

2. System asks actor for the subsystem/ component and LAV id, under consideration.

3. Actor/s provides the ID to the system.

4. System displays the read-only component history/ diagnosis results to the actor

Alternative Flows:

None

Related Use-Cases: None (Stand alone)

Frequency of usage:

Level of operation: LAV, Battalion, MEB, MEF, Sea Base, FSSG, Company, Division, Platoon, O, I and D maintenance levels

Data Used: Ids of Unit, LAV and subsystem/ component.

Data Generated: Read only report of component details and history e.g. product code (numerical), criticality index (numerical), expiry date (date format), past diagnosis result including dates and times (date-time format), resolution (text) etc.

Algorithms used: Database search and retrieval of LAV component details

Decision support tools: Display of results (Front end)

Use Case 2: Prognosis of the health of an LAV

Precondition: System has been carrying out the prognosis of the health of different sub systems in the LAV

Actors: Requestors in the LAV (User/ Non user) e.g. LAV mechanic, Bn level APSSA, MEB level APSSA, MEF level APSSA, Sea Base level APSSA, (Commanders at Company, Division, Platoon and FSSG levels)

Goal: To attempt to monitor the health of an LAV, on the whole, based on health of its constituent subsystems

Flow of events:

1. Actors at levels above query component history database to determine health of an LAV
2. System processor at respective levels check database to determine all the critical sub systems in the LAV and further the health of each of those critical sub systems (based of prognosis or diagnosis status)
3. Draw inference about health of LAV based on reports above

Alternative Flows:

None.

Related Use-Cases: Diagnosis of subsystem at LAV level, Diagnosis of subsystem at Bn level, Diagnosis of subsystem at MEB level, Diagnosis of subsystem at MEF level, Diagnosis of subsystem at Sea Base level

Frequency of usage: TBD

Level of operation: LAV, Bn, MEB, MEF, Sea Base (Company, Division, Platoon, FSSG)

Data Used: Unit and LAV id's (numerical)

Data Generated: Display of health status of LAV subsystems (text), their criticality indices (numerical) and health status of LAV on the whole based on that information (text)

Algorithms used: Retrieval of health status of every subsystem in the LAV, given the LAV id, and further inferring the health status of the LAV based on that information

Decision support tools: Display health status of LAV, on the whole, based on criticality of sub systems and their respective health status

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Use Case 3: Authenticate received field signals

Precondition: Employment of some wireless technology and multiplexing technique for communication between signals from the field (sensor data stream or PDA) and the APSSA at Bn level. (Sensor data stream to be uploaded to Bn level periodically or on breach of thresholds). Receiver system is in place at the APSSA location (Bn) to receive the signals and pre-process it.

Actors: APSSA (Bn level)

Goal: To authenticate the source of the sensor data stream or PDA form from the field to make sure that it originates from validated LAVs/ personnel.

Flow of events:

1. Receiver at Bn level system processor uploads sensor data stream from the LAV level storage when the threshold is breached (or periodically as the case may be) OR receives the PDA signal from the LAV mechanic

2. Bn level APSSA down converts/ demodulates/ decodes received signals (wireless transmission aspects)

3. Bn level APSSA checks platoon/ division/ unit id in decoded message to verify/ authenticate sender

4. (If successful) Bn level APSSA stores data in Bn level database

Alternative Flows:

5. (If not) System ignores received signal

Related Use-Cases: Report out of ordinary event, Process PDA form, Diagnosis of subsystem at Bn

Frequency of usage: TBD

Level of operation: Bn

Data Used: Ids of Platoon, Company, Division, Battalion, LAV and subsystem/ component (numerical), subsystem sensor data stream or PDA form (digitized)

Data Generated: Dates and times of data upload (date-time format), volume of data (numerical), mileage of LAV (numerical), details of subsystem/ component that is source of data stream e.g. product code (numerical), criticality index (numerical) etc.

Algorithms used: Authentication procedure to validate data source, Wireless reception and decoding techniques

Decision support tools: Alert to Bn APSSA of incoming data stream, Authentication procedure status notification to Bn APSSA

Use Case 4: Process PDA form at Bn level

Precondition: Received PDA signal from field (Report out of ordinary event) has been authenticated successfully, decoded and passed here.

Actors: APSSA (Battalion level)

Goal: To attempt to analyze the information received from the PDA that gives further description about the failure (or impending failure) of the subsystem, with a view to diagnose the problem successfully

Flow of events:

4. APSSA at Bn level analyzes PDA form received from field for details identifying LAV, sub system, component (if data available) etc for purposes of diagnosis

5. APSSA locates LAV and sub system details in database at Bn level

6. APSSA time stamps PDA signal reception and records received information in database at Bn level

Alternative Flows:

None

Related Use-Cases: Report out of ordinary event, Authenticate received field signals, Diagnosis of subsystem at Bn

Frequency of usage: TBD

Level of operation: Battalion

Data Used: Ids of LAV and subsystem/ component (numerical), Received PDA form from the LAV (Out of ordinary event report) (alphanumeric)

Data Generated: Display of analysis results e.g. nature of problem (text), potential resolution measures (text) etc and relevant component details e.g. product code (numerical), criticality index (numerical), expiry date (date format)

Algorithms used: Bn level database search and retrieval of LAV subsystem data
System analysis algorithm of PDA form, Database update on information received

Decision support tools: Display of analysis results (Front end), Alert to APSSA (Bn level) of analysis results/ potential corrective solutions

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Use Case 5: Escalate diagnosis from Bn to MEB

Precondition: Wireless communication and plug & play facility, and inventory flow channel is in place between the Bn and MEB levels.

Actors: Bn level APSSA, MEB level APSSA

Goal: To upload the data stream/ Bn level diagnosis results and also ship faulty subsystem/ component from Bn to MEB so that MEB level can assist in the diagnosis process.

Flow of events:

1. (If diagnosis attempts at Bn level fail) Bn level APSSA uploads data stream/ supplementary information and ships subsystem/ component to MEB level

Alternative Flows:
None

Related Use-Cases: Diagnosis of subsystem at Bn level, Diagnosis of subsystem at MEB level

Frequency of usage: TBD

Level of operation: Bn

Data Used: Ids of unit, LAV and subsystem/ component (numerical)

Data Generated: Results of diagnosis attempts at Bn level (text) and subsystem sensor data stream (digitized)

Algorithms used: Data uploads on manual triggers (Diagnosis fails at Bn)

Decision support tools: Diagnosis results at Bn level

Use Case 6: Diagnosis of the health of a subsystem at Bn level

Precondition: Subsystem sensor data stream from LAV has been uploaded to Bn and PDA form from LAV mechanic has been analyzed/ processed.

Actors: APSSA (Battalion level)

Goal: To attempt to diagnose the health of a LAV subsystem based on received information from LAV (uploaded data stream and PDA form from LAV mechanic) to determine component that has failed/ will fail.

Flow of events:

1. APSSA (Bn level) retrieves LAV and subsystem information from the Bn database (This information would originate from the processed form (from PDA in the field) and sensor data stream uploaded to the Bn level from the LAV storage database)

2. APSSA (Bn level) studies retrieved information and determines exact nature of problem and resolution measures

3. APSSA (Bn level) checks O level inventory database to see if it has capabilities to resolve successfully (expertise and equipment)

4. (If yes) APSSA (Bn level) triggers use case- Trigger maintenance action by O level

5. System records above action in database

Alternative Flows:

4. (If no) system triggers Use case- Escalate diagnosis to MEB level

5. System records above action in database.

Related Use-Cases: Escalate diagnosis to MEB level, Process PDA form at Bn, Trigger maintenance action by **O level**

Frequency of usage: TBD

Level of operation: Battalion

Data Used: Ids of unit, LAV and subsystem/ component (numerical), Received PDA form from the LAV (Out of ordinary event report) (text) and uploaded data stream from LAV level (digitized)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), results of diagnosis by Bn APSSA e.g. exact nature of problem (text), corrective action taken/ to be taken (text) etc..

Algorithms used: Bn level database search and retrieval of LAV subsystem data
Database update on entering of action taken, O level inventory database check

Decision support tools: Alert to O-level maintenance regarding impending maintenance action, Display results of O level inventory check

Use Case 7: Trigger maintenance action by O-level

Precondition: After the diagnosis of the health of an LAV subsystem has been performed successfully at the Battalion level (and it has been determined that O level can resolve problem) this use case is triggered

Actors: O-level maintenance personnel, Bn level APSSA

Goal: To trigger the initiation of maintenance action by the O level maintenance. Trigger given by the Battalion level

Flow of events:

1. Bn level APSSA enters SMRC code (escalation aide- O level) for subsystem corrective action to be taken at O level

2. Bn level APSSA sends faulty subsystem/ component to O level and notifies it about incoming shipment

3. Bn level APSSA records above action in database

Alternative Flows:
None

Related Use-Cases: Diagnosis of subsystem by Bn level

Frequency of usage: TBD

Level of operation: Bn

Data Used: Data stream from LAV subsystem sensors (digitized) and diagnosis results at Bn level (text), LAV and subsystem id's (numerical)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), SMRC code

Algorithms used: Bn database update of action taken

Decision support tools: Alert to O level maintenance regarding incoming shipment

Use Case 8: Query a sensor (Bit/Byte check)

Precondition: Employment of some wireless technology and multiplexing technique for communication between LAV system processor and the APSSA (Bn level). Transmitter system is in place at the APSSA location (Bn) to send query signal to the LAV system processor. Query to be sent only if normal periodic upload of data from LAV system processor to Bn level does not take place for a particular subsystem.

Actors: APSSA (Battalion level), LAV sensor

Goal: To ping/ trigger the LAV system processor to upload the sensor data stream of the "missing" LAV subsystem to Bn level.

Flow of events:

7. Bn level system processor checks Bn database to determine the time stamp on the last reception from a particular subsystem sensor emanating from the LAV level.

8. (If pre-determined time limit elapsed) Bn level system processor retrieves LAV, subsystem id and criticality index from database. System alerts Bn level APSSA

9. Bn level system processor initiates query to LAV system processor about "missing" subsystem sensor and stamps priority code on query (depending on criticality index)

10. Bn level system processor queues such outgoing queries depending on the priority code

11. Bn level system processor records the query time in database

12. Bn level system processor transmits query signal

Alternative Flows:

2. (If time limit not elapsed) System rests

Related Use-Cases: Upload data stream periodically from LAV to Bn level

Frequency of usage: Whenever 60 minute uploads do not take place

Level of operation: Battalion

Data Used: Ids of unit, LAV and subsystem/ component (numerical), criticality index of subsystem (numerical)

Data Generated: Priority code to be stamped on query (numerical) ping command to subsystem sensor (alphanumeric)

Algorithms used: Bn level database monitoring to determine any "missing" subsystem sensors (sensor signal reception overdue)

Decision support tools: Alert to Bn level APSSA on elapsing of time limit since last reception (Bn level)

Use Case 9: Report out of ordinary event

Precondition: The mechanic (requestor) in the LAV has detected the malfunctioning sub system and determined that he needs assistance from Bn level mechanic (either ship component to Bn level from LAV level or ship replacements or expertise to LAV level from Bn level)

Actors: LAV requestor (user/ non user) e.g. LAV mechanic

Goal: To seek assistance from Bn level in troubleshooting/ diagnosis of the faulty sub system if the LAV mechanic is unable to troubleshoot it himself

Flow of events:

1. The requestor in the LAV (user/ non-user) fills PDA form describing details of sub system abnormality observed in the LAV. (Contains information related to either shipping component to Bn level or shipping replacements/ expertise from Bn level- Refer use case Subsystem troubleshooting assistance to LAV mechanic/ Escalate diagnosis to Bn)

2. (If system assistance needed in filling form by non user) The system invokes the assistant (Wizard).

3. The system prompts the information that is needed to assist the non-user in filling PDA form

4. The **non-user** fills the form and submits for transmission from LAV to Bn

Alternative Flows:

2. (If system assistance not needed) The **user** fills the form and submits for transmission from LAV to Bn

Related Use-Cases: Diagnosis of subsystem by LAV mechanic, Subsystem troubleshooting assistance/ Escalate diagnosis to Bn from LAV, Authentication of received signals at Bn

Frequency of usage: TBD

Level of operation: LAV

Data Used: Ids of unit, LAV and subsystem/ component (numerical)

Data Generated: Dates and times of reporting (date-time format), mileage of LAV (numerical), description of problem (text), failure mode/ category of problem) (text) etc.

Algorithms used: System assistance (user prompts) in filling PDA form

Decision support tools: None. (Personal decision by LAV mechanic)

Use Case 10: Diagnosis of the health of a subsystem at LAV level

Precondition: LAV level system processor has extracted appropriate critical parameters from sub system sensor data stream and determined that they fall within failure range

Actors: Requestors in the LAV (User/ Non user) e.g. LAV mechanic

Goal: To attempt to diagnose the health of a LAV subsystem by LAV mechanic based on subsystem sensor data stream, to determine component that has failed/ will fail.

Flow of events:

1. LAV level system processor alerts LAV mechanic about the problem (Alarms)

2. LAV system processor alerts Battalion level system processor and uploads contents of LAV black box/ storage to the Bn level database (This is triggered by threshold breach only)

3. LAV mechanic attempts to trouble shoot the problem.

4. (If successful) LAV mechanic records corrective action in database.
(If LAV mechanic determines malfunctioning component but does not have resources to correct it on the field, he ships component to Bn level. LAV mechanic alerts Bn level of incoming shipment. Record action in LAV database)

Alternative Flows:

4. (If LAV mechanic unable to troubleshoot problem) he triggers Use case- Subsystem trouble shooting assistance/ Escalate diagnosis to Bn from LAV. Records action in database.

Related Use-Cases: Prognosis of subsystem at LAV, Subsystem troubleshooting assistance/ Escalate diagnosis to Bn from LAV, Report out of ordinary event

Frequency of usage: TBD

Level of operation: LAV

Data Used: Data stream from subsystem sensors (analog), LAV and subsystem id's (numerical)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), results of diagnosis by mechanic including dates and times of action taken (date-time format), exact nature of problem (text), corrective action taken/ to be taken (text) etc.

Algorithms used: Database update on entering of action taken, Uploading of data stream to Bn level

Decision support tools: Alert to Bn level on threshold breach

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Use Case 11: Subsystem troubleshooting assistance to LAV mechanic/ Escalate diagnosis to Bn level

Precondition: LAV mechanic is unable to troubleshoot LAV subsystem malfunctioning (sensor data stream having breached the threshold level) on his own.

Actors: Bn level APSSA, LAV requestor (User/ Non-user) e.g. LAV mechanic

Goal: To decide flow of information/ inventory for LAV subsystem troubleshooting assistance viz. Bn to LAV or vice-versa. Specifically, whether replacements/ expertise will be shipped from Bn to LAV or whether faulty subsystem/ component will be shipped to Bn from LAV.

Flow of events:

12. LAV mechanic determines if malfunctioning sub system requires Bn level mechanic to visit LAV or component replacement to be shipped to LAV (or if subsystem/ component should be shipped to Bn level)

13. (If flow required from Bn to LAV) LAV mechanic sends request to Bn for sending mechanic down to LAV. Trigger Use Case- Report out of ordinary event (for requesting such assistance). Record above action in LAV database.

Alternative Flows:

2. (If flow required from LAV to Bn) LAV mechanic ships subsystem/ component to Bn level. Also trigger Use Case- Report out of ordinary event (for providing further information on faulty subsystem) Record request in LAV database

Related Use-Cases: Report out of ordinary event, Diagnosis of subsystem by LAV mechanic

Frequency of usage: TBD

Level of operation: LAV

Data Used: Ids of unit, LAV and subsystem/ component (numerical), Data stream from subsystem sensors (analog), Diagnosis results by LAV mechanic (text)

Data Generated: Tentative corrective measures for e.g. mechanic expertise from Bn needed or component replacement from Bn needed and level at which malfunctioning can be resolved (i.e. LAV or Bn) (All text)

Algorithms used: Database update of information recorded

Decision support tools: None (Personal decision by LAV mechanic on scrutiny of subsystem)

Use Case 12: Prognosis of the health of a subsystem at LAV level

Precondition: LAV level system processor is in place for monitoring the data stream from the subsystem level sensors in order to detect breach of thresholds.

Actors: Requestors in the LAV (User/ Non user) e.g. LAV mechanic, sensor

Goal: To attempt to continuously monitor the health of a LAV subsystem based on subsystem sensor data stream

Flow of events:

1. LAV system processor identifies sub system from which the sensor data is received

2. LAV system processor locates the sub system entry in LAV black box/ data storage device

3. LAV system processor checks database to determine critical parameters and failure range for the sub system

4. LAV system processor extracts appropriate critical parameters from sensor data stream

5. LAV system processor checks if extracted parameters fall in failure range

6. (If yes) LAV system processor alerts LAV requestor (User/ Non user). Refer Use Case: Diagnosis of subsystem at LAV level

7. LAV system processor time stamps sensor data stream reception and records it as well as other messages e.g. threshold breach, mechanic alert etc. in LAV black box/ data storage device

Alternative Flows:

6. (If no) LAV system processor continues recording data stream

Related Use-Cases: Diagnosis of subsystem at LAV level

Frequency of usage: TBD

Level of operation: LAV

Data Used: Data stream from subsystem sensors (analog), critical parameters for a particular sub system and its threshold values (numerical), LAV and subsystem id's (numerical)

Data Generated: Visual representations of the critical parameters being monitored in the sensor data stream (analog) and health status messages (Well/ Fail) depending on breach of thresholds (text)

Algorithms used: Threshold detection in subsystem sensor data stream, Data stream storage in LAV database, Database search and retrieval of subsystem details, Extraction of critical parameters from sensor data stream

Decision support tools: Visual representations of the critical parameters being monitored in the sensor data stream (Front end) and other subsystem details to LAV mechanic, Alert to LAV mechanic when breach occurs

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Use Case 13: Upload data stream periodically from LAV to Bn

Precondition: Wireless communication facility is in place between the LAV and Bn level system processors.

Actors: Bn level APSSA

Goal: To upload the data stream from system processor at LAV level to Bn level so that Bn level can assist in the diagnosis process.

Flow of events:

1. LAV level system processor uploads data to Bn level at the appropriate periodic time intervals

2. System records above action/s in LAV database

Alternative Flows:
None

Related Use-Cases: None

Frequency of usage: 60 minute intervals

Level of operation: LAV

Data Used: Ids of unit, LAV and subsystem (numerical), pre-determined period of data uploads (time) e.g. 60 minutes

Data Generated: Data stream from the subsystem sensor (digitized analog), subsystem details e.g. product code (numerical), criticality index (numerical), recent actions taken (text), health status (text)

Algorithms used: Periodic self-triggers for data uploads

Decision support tools: None

Use Case 14: Take Condition-Based Maintenance action at appropriate level

Precondition: The APSSA at the appropriate organizational level triggers initiation of maintenance action at corresponding maintenance level based on diagnostic result of subsystem from particular LAV

Actor(s): Maintenance person at appropriate level, APSSA at corresponding level, RM Manager

Goal: To successfully perform condition based maintenance action based on information given.

Flow of events

1. The APSSA alerts the maintenance person of approaching LAV
2. The maintenance person queries information of the LAV component that needs to be repaired from component history database
3. The maintenance person checks the database if the component is available
4. (If yes) The maintenance person performs the maintenance actions

Alternative Flows:

4. (If no) Maintenance person triggers the request for the component to the RM system

Related Use Cases: Trigger maintenance action by O/I/D level, Report the maintenance action at appropriate level, Trigger request management.

Frequency: TBD

Level of Operation: Battalion/ MEB/ MEF/ Sea Base Level

Data used: Historical data of the component (text), Recommendation from the APSSA (text)

Data Generated: Ordering status for the component (text), maintenance action status (text)

Algorithm Used: Query for historical data from database, check the availability of the component.

Decision Support Tools: The availability of the components.

Use Case 15: Report the Maintenance Action at appropriate level

Precondition: After the maintenance has been performed, the maintenance person at the maintenance level is ready to record the action taken into the system (GUI display).

Actors: Maintenance person at appropriate level, APSSA person at corresponding organizational level

Goal: To successfully record the maintenance action as a reference for the future.

Flow of events

1. The component history database asks for the ID and password from the maintenance person before recording the maintenance action
2. If (password = correct) Database displays the form to be filled by the mechanic about the maintenance activity.
3. Database stores information that is entered by the maintenance person

Alternative Flows:

2. If (password = incorrect) ask the user to re-enter

Related Use Cases: Take the corrective maintenance action at appropriate level, Take the preventive maintenance action at appropriate level, Take condition based maintenance action at appropriate level

Frequency: TBD

Level of Operation: Bn/ MEB/ MEF/ Sea Base

Data Used: User ID and Password (alphanumeric)

Data generated: Maintenance action status (text)

Algorithm Used: Database update of action taken

Decision Support Tools: Maintenance action status to be recorded

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Use Case 16: Take the corrective maintenance action at appropriate level

Precondition: The APSSA at appropriate organizational level triggers initiation of maintenance action at corresponding level based on diagnostic result of subsystem from particular LAV.

Actor(s): Maintenance person at appropriate level, APSSA at corresponding organizational level, RM manager

Goal: To successfully perform corrective maintenance action based on information given.

Flow of events:

1. The APSSA at appropriate level alerts the maintenance person at corresponding level of required service (incoming shipment)

2. The maintenance person queries information of the LAV component/ subsystem that needs to be repaired from the component history database

3. The maintenance person checks if necessary tools (or replacements) are available

4. (If yes) Maintenance person performs the maintenance actions

Alternative Flows:

5. (If no) Maintenance person triggers the request for the component to the RM Manager

Related Use Cases: Trigger maintenance action by O/I/D levels, Report the maintenance action at appropriate level, Trigger request management.

Frequency: TBD

Level of operation: Battalion/ MEB/ MEF/ Sea Base level

Data used: Historical data of the component (text), Diagnosis results from APSSA (text), Recommendation from the APSSA (text), Availability of the component at each level (various).

Data Generated: Ordering status for the component (text), maintenance action status (text)

Algorithm used: Query for historical data from database, check the availability of the component.

Decision support tools: Availability of the components.

Use Case 17: Trigger request management

Precondition: The mechanics at particular maintenance level checks the availability of the component that needs to be repaired or changed.

Actors: Maintenance person at O level, Maintenance person at I level, Maintenance person at D level, Request Management Manager

Goal: To support the needs of components by the mechanics at a particular level of maintenance.

Flow of events

1. The mechanic in particular maintenance level check the availability of the component in the warehouse or through the component availability database
2. If (component = available) the mechanic takes the component from the warehouse and update the remaining number of components into the inventory database.

Alternative Flows:

1. If (component = unavailable) the mechanic requests for the component online to the Request Management Manager.
2. The Request Management Manager updates the order activity into the inventory database.

Related Use Cases: Take the Corrective Maintenance Action (O level), Take the Corrective Maintenance Action (I level), Take the Corrective Maintenance Action (D level), Condition Based Maintenance Action (O level), Condition Based Maintenance Action (I level), Condition Based Maintenance Action (D level), Take the Preventive Maintenance Action (O level), Take the Preventive Maintenance Action (I level)

Frequency: TBD

Level of Operation: Battalion Level, MEB level, MEF level

Data Used: the availability of the component at particular level

Data generated: the remaining number of the components.

Algorithm Used: request for the availability of the component, upload the remain number of the component into the inventory database

Decision Support Tools: display the availability of the particular component at particular level.

Use Case 18: Take the preventive maintenance action at appropriate level

Precondition: APSSA at Bn/ MEB level reads component history/ diagnosis results from database. Then APSSA then triggers the preventive maintenance action at the corresponding maintenance level (O/I).

Actor(s): Maintenance person at O/I level, APSSA at corresponding level (Bn/ MEB), RM Manager

Goal: To successfully perform preventive maintenance action based on historical information of component/ subsystem

Flow of events

1. The APSSA alerts the maintenance person of preventive action to be taken on a particular subsystem/ component (based on history data)
2. The maintenance person queries information of the LAV component that need to be repaired from component history database
3. Maintenance person rechecks if maintenance action required
4. (If yes) The maintenance person checks if tools/ replacements available
5. (If yes) The maintenance person performs the preventive maintenance actions

Alternative Flows:

4. (If no) No further action
5. (If no) Maintenance person triggers the request for the component to the RM manager

Related Use Cases: View diagnosis result/ read component history database, Report the maintenance action at appropriate level, Trigger request management, Trigger maintenance action by O/I levels

Frequency: TBD

Level of operation: Battalion/ MEB

Data used: Historical data of the component (text), Recommendation from the APSSA (text), Availability of the component at each level (text)

Data Generated: Ordering status for the component (text), the maintenance action status (text)

Algorithms Used: Query for historical data from database, check the availability of the component.

Decision Support Tools: The availability of the component

Use Case 19: Diagnosis of the health of a subsystem at MEB level

Precondition: The Bn level has diagnosed the subsystem and determined that it needs to be escalated to the MEB level as it (Bn and O levels) do not have sufficient resources to successfully resolve the problem

Actors: MEB level APSSA

Goal: To attempt to diagnose the health of a subsystem at MEB level based on received information from LAV and Bn level to determine component that has failed/ will fail

Flow of events:

1. APSSA (MEB level) retrieves LAV and subsystem information from the MEB database (This would originate from the consolidated information from Bn and LAV levels)

2. APSSA (MEB level) studies retrieved information and determines exact nature of problem and resolution measures

3. APSSA (MEB level) checks I level inventory database to see if it has capabilities to resolve successfully (expertise and equipment)

4. (If yes) APSSA (MEB level) triggers use case- Trigger maintenance action by I level

5. System records above action in database

Alternative Flows:

4. (If no) system triggers Use case- Escalate diagnosis to MEF level

5. System records above action in database.

Related Use-Cases: Escalate diagnosis to MEF level from MEB, Trigger maintenance action by **I level,** Escalate diagnosis to MEB level from Bn

Frequency of usage: TBD

Level of operation: MEB

Data Used: Ids of unit, LAV and subsystem/ component (numerical), Consolidated information from Bn and LAV levels (numerical, digitized and text)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), results of diagnosis by MEB APSSA e.g. exact nature of problem (text), corrective action taken/ to be taken (text) etc..

Algorithms used: MEB level database search and retrieval of LAV subsystem data
Database update on entering of action taken, I level inventory database check

Decision support tools: Alert to I-level maintenance regarding impending maintenance action, Display results of I level inventory check

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Use Case 20: Trigger maintenance action by I-level

Precondition: After the diagnosis of the health of an LAV subsystem has been performed successfully at the MEB level (and it has been determined that I level can resolve problem) this use case is triggered

Actors: I-level maintenance personnel, MEB level APSSA

Goal: To trigger the initiation of maintenance action by the I level maintenance. Trigger given by the MEB level

Flow of events:

1. MEB level APSSA enters SMRC code (escalation aide- I level) for subsystem corrective action to be taken at I level

2. MEB level APSSA sends faulty subsystem/ component to I level and notifies it about incoming shipment

3. MEB level APSSA records above action in database

Alternative Flows:
None

Related Use-Cases: Diagnosis of subsystem by MEB level

Frequency of usage: TBD

Level of operation: MEB

Data Used: Data stream from LAV subsystem sensors (digitized) and diagnosis results at MEB level (text), LAV and subsystem id's (numerical)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), SMRC code

Algorithms used: MEB database update of action taken

Decision support tools: Alert to I level maintenance regarding incoming shipment

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Use Case 21: Trigger maintenance action by D-level

Precondition: After the diagnosis of the health of an LAV subsystem has been performed successfully at the MEF/ Sea Base level (and it has been determined that D level can resolve problem) this use case is triggered

Actors: D-level maintenance personnel, MEF level APSSA, Sea Base level APSSA

Goal: To trigger the initiation of maintenance action by the D level maintenance. Trigger given by the MEF/ Sea Base levels

Flow of events:

1. MEF/ Sea Base level APSSA enters SMRC code (escalation aide- D level) for subsystem corrective action to be taken at D level

2. MEF/ Sea Base level APSSA sends faulty subsystem/ component to D level and notifies it about incoming shipment

3. MEF/ Sea Base level APSSA records above action in database

Alternative Flows:
None

Related Use-Cases: Diagnosis of subsystem by MEF level/ Diagnosis of subsystem at Sea Base level

Frequency of usage: TBD

Level of operation: MEF or Sea Base

Data Used: Data stream from LAV subsystem sensors (digitized) and diagnosis results at MEF/ Sea Base level (text), LAV and subsystem id's (numerical)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), SMRC code

Algorithms used: MEF database update of action taken/ Sea Base database update of action taken

Decision support tools: Alert to D level maintenance regarding incoming shipment

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Use Case 22: Diagnosis of the health of a subsystem at MEF level

Precondition: The MEB level has diagnosed the subsystem and determined that it needs to be escalated to the MEF level as it (MEB and I levels) do not have sufficient resources to successfully resolve the problem

Actors: MEF level APSSA

Goal: To attempt to diagnose the health of a subsystem at MEF level based on received information from LAV, Bn and MEB levels to determine component that has failed/ will fail

Flow of events:

1. APSSA (MEF level) retrieves LAV and subsystem information from the MEF database (This would originate from the consolidated information from MEB, Bn and LAV levels)

2. APSSA (MEF level) studies retrieved information and determines exact nature of problem and resolution measures

3. APSSA (MEF level) checks D level inventory database to see if it has capabilities to resolve successfully (expertise and equipment)

4. (If yes) APSSA (MEF level) triggers use case- Trigger maintenance action by
D level

5. System records above action in database

Alternative Flows:

4. (If no) system triggers Use case- Escalate diagnosis to Sea Base level

5. System records above action in database.

Related Use-Cases: Escalate diagnosis to MEF level from MEB, Trigger maintenance action by **D level,** Escalate diagnosis to Sea Base level from MEF

Frequency of usage: TBD

Level of operation: MEB

Data Used: Ids of unit, LAV and subsystem/ component (numerical), Consolidated information from MEB, Bn and LAV levels (numerical, digitized and text)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), results of diagnosis by MEF APSSA e.g. exact nature of problem (text), corrective action taken/ to be taken (text) etc..

Algorithms used: MEF level database search and retrieval of LAV subsystem data
Database update on entering of action taken, D level inventory database check

Decision support tools: Alert to D-level maintenance regarding impending maintenance action, Display results of D level inventory check

---

Use Case 23: Escalate diagnosis from MEB to MEF

Precondition: Wireless communication and plug & play facility, and inventory flow channel is in place between the MEB and MEF levels.

Actors: MEF level APSSA, MEB level APSSA

Goal: To upload the data stream/ MEB level diagnosis results and also ship faulty subsystem/ component from MEB to MEF so that MEF level can assist in the diagnosis process.

Flow of events:

1. (If diagnosis attempts at MEB level fail) MEB level APSSA uploads data stream/ supplementary information and ships subsystem/ component to MEF level

Alternative Flows:
None

Related Use-Cases: Diagnosis of subsystem at MEB level, Diagnosis of subsystem at MEF level

Frequency of usage: TBD

Level of operation: MEB

Data Used: Ids of unit, LAV and subsystem/ component (numerical)

Data Generated: Results of diagnosis attempts at MEB level (text) and subsystem sensor data stream (digitized)

Algorithms used: Data uploads on manual triggers (Diagnosis fails at MEB)

Decision support tools: Diagnosis results at MEB level

Use Case 24: Trigger request management

Precondition: The mechanics at particular maintenance level checks the availability of the component that needs to be repaired or changed.

Actors: Maintenance person at O level, Maintenance person at I level, Maintenance person at D level, Request Management Manager

Goal: To support the needs of components by the mechanics at a particular level of maintenance.

Flow of events

3. The mechanic in particular maintenance level check the availability of the component in the warehouse or through the component availability database
4. If (component = available) the mechanic takes the component from the warehouse and update the remaining number of components into the inventory database.

Alternative Flows:

3. If (component = unavailable) the mechanic requests for the component online to the Request Management Manager.
4. The Request Management Manager updates the order activity into the inventory database.

Related Use Cases: Take the Corrective Maintenance Action (O level), Take the Corrective Maintenance Action (I level), Take the Corrective Maintenance Action (D level), Condition Based Maintenance Action (O level), Condition Based Maintenance Action (I level), Condition Based Maintenance Action (D level), Take the Preventive Maintenance Action (O level), Take the Preventive Maintenance Action (I level)

Frequency: TBD

Level of Operation: Battalion Level, MEB level, MEF level

Data Used: the availability of the component at particular level

Data generated: the remaining number of the components.

Algorithm Used: request for the availability of the component, upload the remain number of the component into the inventory database

Decision Support Tools: display the availability of the particular component at particular level.

Use Case 25: Diagnosis of the health of a subsystem at Sea Base level

Precondition: The MEF level has diagnosed the subsystem and determined that it needs to be escalated to the Sea Base level as it (MEF and D levels) do not have sufficient resources to successfully resolve the problem

Actors: Sea Base level APSSA

Goal: To attempt to diagnose the health of a subsystem at Sea Base level based on received information from LAV, Bn, MEB and MEF levels to determine component that has failed/ will fail

Flow of events:

1. APSSA (Sea Base level) retrieves LAV and subsystem information from the Sea Base database (This would originate from the consolidated information from MEB, MEF, Bn and LAV levels)

2. APSSA (Sea Base level) studies retrieved information and determines exact nature of problem and resolution measures

3. APSSA (Sea Base level) checks D level inventory database to see if it has capabilities to resolve successfully (expertise and equipment)

4. (If yes) APSSA (Sea Base level) triggers use case- Trigger maintenance action by D level

5. APSSA (Sea Base level) records above action in database

Alternative Flows:

4. (If no) system triggers Use case- Trigger Request Management (OA processes) to external suppliers S1 and Sn

5. System records above action in database.

Related Use-Cases: Trigger maintenance action by **D level,** Escalate diagnosis to Sea Base level from MEF, Trigger Request Management to external suppliers

Frequency of usage: TBD

Level of operation: Sea Base

Data Used: Ids of unit, LAV and subsystem/ component (numerical), Consolidated information from MEF, MEB, Bn and LAV levels (numerical, digitized and text)

Data Generated: Subsystem details e.g. product code (numerical), criticality index (numerical), expiry date (date format), results of diagnosis by Sea Base APSSA e.g. exact nature of problem (text), corrective action taken/ to be taken (text) etc.

Algorithms used: Sea Base level database search and retrieval of LAV subsystem data
Database update on entering of action taken, D level inventory database check

Decision support tools: Alert to D-level maintenance regarding impending maintenance action, Display results of D level inventory check

7.3 Appendix 3 - Data Mining

Data mining, the extraction of hidden predictive information from large databases, is a powerful new technology with great potential to help organizations focus on the most important information in their data warehouses. Data mining tools predict future trends and behaviors, allowing businesses to make proactive, knowledge-driven decision supports. The automated, prospective analyses offered by data mining move beyond the analyses of past events provided by retrospective tools typical of decision support systems. Data mining tools can answer business and strategy questions that traditionally were time consuming to resolve.

7.3.1 The Foundations and Scope of Data Mining

Data mining techniques are the result of a long process of research and product development. This evolution began when business data was first stored on computers, continued with improvements in data access, and more recently generated technologies that allow users to navigate through their data in real time. Data mining takes this evolutionary process beyond retrospective data access and navigation to prospective and proactive information delivery. Data mining is ready for application in the various businesses because it is supported by three main technologies that are now sufficiently mature:

- Massive data collection
- Powerful multiprocessor computers
- Data mining algorithms

The core components of data mining technology have been under development, in research areas such as statistics, artificial intelligence, and machine learning. Today, the maturity of these techniques, coupled with high-performance relational database engines and broad data integration efforts, make these technologies practical for current data warehouse environments. Finally, data mining technology can generate new business opportunities by providing the following two main capabilities:

- Automated prediction of trends and behaviors: data mining automates the process of finding predictive information in large databases.
- Automated discovery of previously unknown patterns: data mining tools sweep through databases and identify previously hidden patterns in one step.

In the software and hardware point of view, data mining techniques can yield the benefits of automation on existing platforms, and can be implemented on new systems as existing platforms are upgraded and new products developed. When data mining tools are implemented on high performance parallel processing systems, they can analyze massive databases in minutes. Faster processing means that users can automatically experiment with more models to understand complex data. High speed makes it practical for users to analyze huge quantities of data. Larger databases, in turn, yield improved predictions.

7.3.2 Data Mining, Machine Learning, and Statistics

Data mining takes advantage of advances in the fields of artificial intelligence (AI) and statistics. Both disciplines have been working on problems of pattern recognition and classification. Both communities have made great contributions to the understanding and application of neural nets and decision trees.
Data mining does not replace traditional statistical techniques. Rather, it is an extension of statistical methods that is in part the result of a major change in the statistics community. The development of most statistical techniques was, until recently, based on elegant theory and analytical methods that worked quite well on the modest amounts of data being analyzed. The increased power of computers and their lower cost, coupled with the need to analyze enormous data sets with millions of rows, have allowed the development of new techniques based on a brute-force exploration of possible solutions [4],[5],[6].

New techniques include relatively recent algorithms like decision trees, and new approaches to older algorithms such as discriminant analysis. By virtue of bringing to bear the increased computer power on the huge volumes of available data, these techniques can approximate almost any functional form or interaction on their own. Traditional statistical techniques rely on the modeler to specify the functional form and interactions.
The key point is that data mining is the application of these and other AI and statistical techniques to common business problems in a fashion that makes these techniques available to the skilled knowledge worker as well as the trained statistics professional. Data mining is a tool for increasing the productivity of people trying to build predictive models.

7.3.3 Data Mining Applications

Data mining is increasingly popular because of the substantial contribution it can make. It can be used to control costs as well as contribute to performance increases.

Many organizations are using data mining to help manage all phases of the product or customer life cycle, including acquiring new products or customers, increasing revenue from existing products or customers, and maintaining good products or customers. By determining characteristics of products or customers, an organization can apply specific strategies to the groups with similar characteristics.

Data mining also offers value across a broad spectrum of organizations. Telecommunications and credit card companies are two of the leaders in applying data mining to detect fraudulent use of their services. Insurance companies and stock exchanges are also interested in applying this technology to reduce fraud. Medical applications are another fruitful area: data mining can be used to predict the effectiveness of surgical procedures, medical tests or medications. Companies active in the financial markets use data mining to determine market and industry characteristics as well as to predict individual company and stock performance. Retailers are making more use of data mining to decide which products to stock in particular stores (and even how to place them within a store), as well as to assess the effectiveness of promotions and coupons. Pharmaceutical firms are mining large databases of chemical compounds and of genetic material to discover substances that might be candidates for development as agents for the treatments of disease.

7.3.4 Data Mining Models and Algorithms

Most of the models and algorithms discussed in this section can be thought of as generalizations of the standard workhouse of modeling, the linear regression model. Much effort has been expended in the statistics, computer science, artificial intelligence, and engineering communities to overcome the limitations of this basic model. The common characteristic of many of the newer technologies is that the pattern-finding mechanism is data-driven. That is, the relationships are found inductively by the software itself based on the existing data.

The most important thing to remember is that no one model or algorithm can or should be used exclusively. For any given problem, the nature of the data itself will affect the choice of models and algorithms. There is no best model or algorithm. Consequently, it is necessary to require a variety of tools and technologies in order to find the best possible model.

7.3.4.1 Neural Networks

Neural networks are of particular interest because they offer a means of efficiently modeling large and complex problems in which there may be hundreds of predictor variables that have many interactions. Neural nets may be used in classification problems, where the output is a categorical variable, or for regressions, where the output variable is continuous.

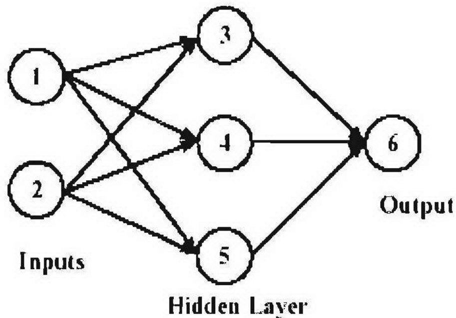

Figure 7.3.1 A Neural Network with One Hidden Layer

A neural network starts with an *input layer*, where each node corresponds to a predictor variable. Each input node is connected to every node in the hidden layer. The nodes in the hidden layer may be connected to nodes in another hidden layer, or to an *output layer*. The output layer consists of one or more response variables.

7.3.4.2 Decision Trees

Decision trees are a way of representing a series of rules that lead to a class or value. Depending on the algorithm, each tree node may have two or more branches. Each branch will lead either to another decision node or to the bottom of the tree, called a leaf node.

By navigating the decision tree, a value or class can be assigned to a case by deciding which branch to take, starting at the root node and moving to each subsequent node until a leaf node is reached. Each node uses the data from the case to choose the appropriate branch.

Decision tree models are commonly used in data mining to examine the data and induce the tree and its rules that will be used to make predictions. A number of different algorithms may be used for building decision trees including CHAID (Chi-squared Automatic Interaction Detection), CART (Classification and Regression Trees), Quest, and C5.0.

Decision trees which are used to predict categorical variables are called classification trees because they place instances in categories or classes. Decision trees used to predict continuous variables are called regression trees. Decision trees make few passes through the data (no more than one pass for each level of the tree) and they work well with many predictor variables. As a consequence, models can be built very quickly, making them suitable for large data sets.

Decision trees handle non-numeric data very well. This ability to accept categorical data minimizes the amount of data transformations and the explosion of predictor variables inherent in neural nets.
Some classification trees were designed for and therefore work best when the predictor variables are also categorical. Continuous predictors can frequently be used even in these cases by converting the continuous variable to a set of ranges. Some decision trees do not support continuous response variables, in which case the response variables in the training set must also be ranged to output classes.

7.3.4.3 K-Nearest Neighbors

When trying to solve new problems, some algorithms often look at solutions to similar problems that they have previously solved. K-nearest neighbor (k-NN) is a classification technique that uses a version of this same method. It decides in which class to place a new case by examining some number — the "k" in k-nearest neighbor — of the most similar cases or neighbors. It counts the number of cases for each class, and assigns the new case to the same class to which most of its neighbors belong.

The first thing to be done to apply k-NN is to find a measure of the distance between attributes in the data and then calculate it. While this is easy for numeric data, categorical variables need special handling. Once the distance between cases is calculated, then, select the set of already classified cases to use as the basis for classifying new cases, decide how large a neighborhood in which to do the comparisons, and also decide how to count the neighbors themselves.

K-NN puts a large computational load on the computer because the calculation time increases as the factorial of the total number of points. While it's a rapid process to apply a decision tree or neural net to a new case, k-NN requires that a new calculation be made for each new case. To speed up k-NN, frequently all the data is kept in memory. Memory-based reasoning usually refers to a k-NN classifier kept in memory.

K-NN models are very easy to understand when there are few predictor variables. They are also useful for building models that involve non-standard data types, such as text. The only requirement for being able to include a data type is the existence of an appropriate metric.

7.3.4.4 K-Means Clustering

A non-hierarchical approach to forming good clusters is to specify a desired number of clusters, say, k, then assign each case to one of k clusters so as to minimize a measure of dispersion within the clusters. A very common measure is the sum of distances or sum of squared Euclidean distances from the mean of each cluster. The problem can be set up as an integer programming problem but because solving integer programs with a large number of variables is time consuming, clusters are often computed using a fast, heuristic method that generally produces good solutions.

The k-means algorithm starts with an initial partition of the cases into k clusters. Subsequent steps modify the partition to reduce the sum of the distances for each case from the mean of the cluster to which the case belongs. The modification consists of allocating each case to the nearest of the k means of the previous partition. This leads to a new partition for which the sum of distances is strictly smaller than before. The improvement step is repeated until the improvement is very small. The method is very fast. There is a possibility that the improvement step leads to fewer than k partitions. In this situation one of the partitions (generally the one with the largest sum of distances from the mean) is divided into two or more parts to reach the required number of k partitions. The algorithm can be rerun with different randomly generated starting partitions to reduce the chances of the heuristic producing a poor solution. Generally the number of true clusters in the data is not known. Therefore, it is a good idea to run the algorithm with different values for k that are near the number of clusters one expects from the data to see how the sum of distances reduces with increasing values of k.

7.3.4.5 Discriminant Analysis

Discriminant analysis is the oldest mathematical classification technique, having been first published by R. A. Fisher in 1936 to classify the famous Iris botanical data into three species. It finds hyper planes (e.g., lines in two dimensions, planes in three, etc.) that separate the classes. The resultant model is very easy to interpret because all the user has to do is determine on which side of the line (or hyper-plane) a point falls. Training is simple and scalable. The technique is very sensitive to patterns in the data.
Even the boundaries that separate the classes are all linear forms (such as lines or planes), recent versions of discriminant analysis address some of these problems by allowing the boundaries to be quadratic as well as linear, which significantly increases the sensitivity in certain cases. There are also techniques that allow the normality assumption to be replaced with an estimate of the real distribution.

7.3.5 Data Mining Classification

7.3.5.1 Classification (Supervised Learning)

Classification in data mining is a supervised learning. Supervised learning processes are as follows; first, prepare set of samples which has correct class for the each data, and divide samples into two sets, one is training dataset and the other is test dataset. second, create a model by learning the selected algorithm on the training data, third, validate and evaluate the created model with test dataset and model evaluating methods, and finally, identify a class for the new incoming data.

The aim of classification problems is to identify the characteristics that indicate the group to which each case belongs. This pattern can be used both to understand the existing data and to predict how new instances will behave.
Data mining creates classification models by examining already classified data (cases) and inductively finding a predictive pattern. These existing cases may come from an historical database. Also, they may come from an experiment in which a sample of the entire database is tested in the real world and the results used to create a classifier.

7.3.5.1.1 Classification Algorithms

Among many classification algorithms, following algorithms, linear regression of an indicator matrix, linear discriminant analysis, and quadratic discriminant analysis, are applied in this study.

7.3.5.1.1.1 Linear Regression of an Indicator Matrix

In linear regression of an indicator matrix algorithm, each of the response categories are coded via an indicator variable. This if there are $g = K$ classes, there will be K such indicators Y_k, $k = 1, \ldots, K$, with Yk = 1 if $G = k$ else 0. These are collected together in a vector $Y = (Y_1, Y_2, \ldots, Y_k)$, and the N training instances of these form an $N \times K$ indicator response matrix Y. Y is a matrix of 0's and 1's, with each row having a single 1. Following is a brief process for linear regression of an indicator matrix method.

Creating Y Matrix, $Y = (Y_1, Y_2, \ldots, Y_k)$
Linear Fit: $\hat{Y} = X(X^T X)^{-1} X^T Y$

Coefficient Matrix: $\hat{B} = (X^T X)^{-1} X^T Y$

Compute the Fitted Output: $\hat{f}(x) = [(1, x)\hat{B}]^T$

Classification with identifying the largest component: $\hat{G}(x) = \arg\max_{k \in g} \hat{f}_k(x)$

7.3.5.1.1.2 Linear Discriminant Analysis

Decision theory for classification shows the necessity of the class posteriors $\Pr(G|X)$ for optimal classification. Suppose $f_k(x)$ is the class-conditional density of X in class $G = k$, and let π_k be the prior probability of class k, with $\sum_{k=1}^{K} \pi_k = 1$. A simple application of Bayes theorem gives,

$$\Pr(G = k \mid X = x) = \frac{f_k(x)\pi_k}{\sum_{l=1}^{K} f_l(x)\pi_l}$$

It can be shown that in terms of ability to classify, having the $f_k(x)$ is almost equivalent to having the quantity $\Pr(G=k|X=x)$.
Many techniques are based on models for the class densities;

linear and quadratic discriminant analysis use Gaussian densities;
more flexible mixtures of Gaussians allow for nonlinear decision boundaries;

general nonparametric density estimates for each class density allow the most flexibility;
Naïve Bayes models are a variant of the previous case, and assume that each of the class densities are products of marginal densities; that is, they assume that the inputs are conditionally independent in each class.

Suppose that each class density can be modeled as multivariate Gaussian, shown as following equation;

$$f_k(x) = \frac{1}{(2\pi)^{p/2}|\Sigma_k|^{1/2}} e^{-\frac{1}{2}(x-\mu_k)^T \Sigma_k^{-1}(x-\mu_k)}$$

Linear discriminant analysis (LDA) arises in the special case when it is assumed that the classes have a common covariance matrix $\Sigma_k = \Sigma \ \forall k$.

Following shows brief process of linear discriminant analysis method:

Assume Gaussian distribution
Assume all classes have a common covariance matrix
$\Sigma_k = \Sigma \quad \forall k$
Linear Discriminant Functions

$$\delta_k(x) = x^T \Sigma^{-1} \mu_k - \frac{1}{2}\mu_k^T \Sigma^{-1} \mu_k + \log \pi_k$$

Estimate parameters of the Gaussian distributions using the training dataset
$\hat{\pi}_k = N_k / N$, where N_k is the number of class k observations;

$$\hat{\mu}_k = \sum_{g_i = k} x_i / N_k \ ;$$

$$\hat{\Sigma} = \sum_{k=1}^{K} \sum_{g_i = k} (x_i - \hat{\mu}_k)(x_i - \hat{\mu}_k)^T / (N - K)$$

$$G(x) = \arg\max_k \delta_k(x)$$

7.3.5.1.1.3 Quadratic Discriminant Analysis

In each class density, modeled as multivariate Gaussian, if the Σ_k are not assumed to be equal, then the quadratic discriminant functions can be generated. With this function, quadratic discriminant analysis can be conducted.

Following shows brief process of quadratic discriminant analysis method.

Assume Gaussian distribution
Each class has own covariance matrix

$$\Sigma_k = \sum_{g_i = k} (x_i - \hat{\mu}_k)(x_i - \hat{\mu}_k)^T / N_k$$

Quadratic Discriminant Functions

$$\delta_k(x) = -\frac{1}{2}\log|\Sigma_k| - \frac{1}{2}(x - \mu_k)^T \Sigma_k^{-1}(x - \mu_k) + \log \pi_k$$

Estimate parameters of the Gaussian distributions using the training dataset
$\hat{\pi}_k = N_k / N$, where, N_k is the number of class k observations;

$$\hat{\mu}_k = \sum_{g_i = k} x_i / N_k \ ;$$

$$G(x) = \arg\max_k \delta_k(x)$$

7.3.6 Validation and Dimension Reduction Techniques in Data Mining Model

7.3.6.1 Cross Validation

To evaluate the classification algorithms, cross validation method can be introduced since it is the simplest and most widely used method for estimating prediction error.

With this method, the extra-sample error, $Err = E\left[L\left(Y,\ \tilde{f}(X)\right)\right]$, can be directly estimated.

Since sample data (E0947 SECREPS) are scarce, *K*-fold cross validation is used. This uses part of the available data to fit the model, and a different part to test it. In this study, sample data is split into 5 roughly equal-sized parts. This 5-fold cross validation scenario looks like following figure:

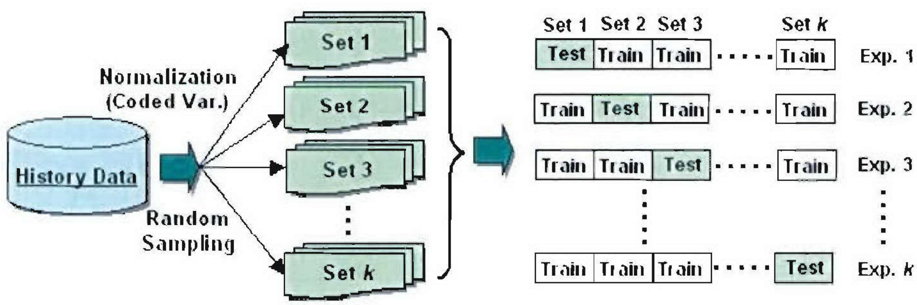

Figure 7.3.2 Cross Validation

7.3.6.2 Principal Component Analysis (Dimension Reduction)

By retaining a subset of the predictors and discarding the rest, subset selection produces a model that is interpretable and has possibly lower prediction error than the full model. In this study, principal component (or Karhunen-Loeve) analysis is used as a dimension reduction method.

The sample covariance matrix is given by $S = X^T X / N$. And the eigen decomposition of $X^T X$ is given by: $X^T X = VDV^T$. Matrix D is a $p \times p$ diagonal matrix in which the diagonal element $D_{ii} = d_i \geq 0$. We can always rearrange D such that $d_i \geq d_j$ if $i < j$. The column vector of V, i.e. the eigenvector v_i, is called the principal component direction of X. X can be transformed into a new variable matrix $Z = XV$, which lies in the space spanned by eigenvectors v_i's. The i^{th} column of Z, $z_i = Xv_i$, is called the i^{th} principle component of X. It's easy to show $Var(z_i) = \frac{d_i}{N}$. Since d_i's are sorted as decreasing sequence, $Var(z_i)$ is also a decreasing sequence.

From the above analysis, we can see that the first principle component direction v_1 is a direction in the original space along which the sample has the most variation. On the contrary, the last component v_p is the direction along which the sample has the least variation. So if we want to reduce the number of predictors from p to $p-k$, the predictors that we need in the new space are the first $p-k$ principle components $z_1, z_2, \ldots, z_{p-k}$.

7.3.7 Applying Data Mining to IDGE Study

Data Mining can be applied as an alternative decision support tool in IDGE architecture. This will support the maintenance strategies, for example, applying different maintenance rules based on the mission/risk for a part or an item (e.g. SECREPS). This will also support the automated O.A. processes in IDGE architecture, for example, applying different business rules (e.g. inventory fulfillment) based on the fill-up strategy for a part or an item.

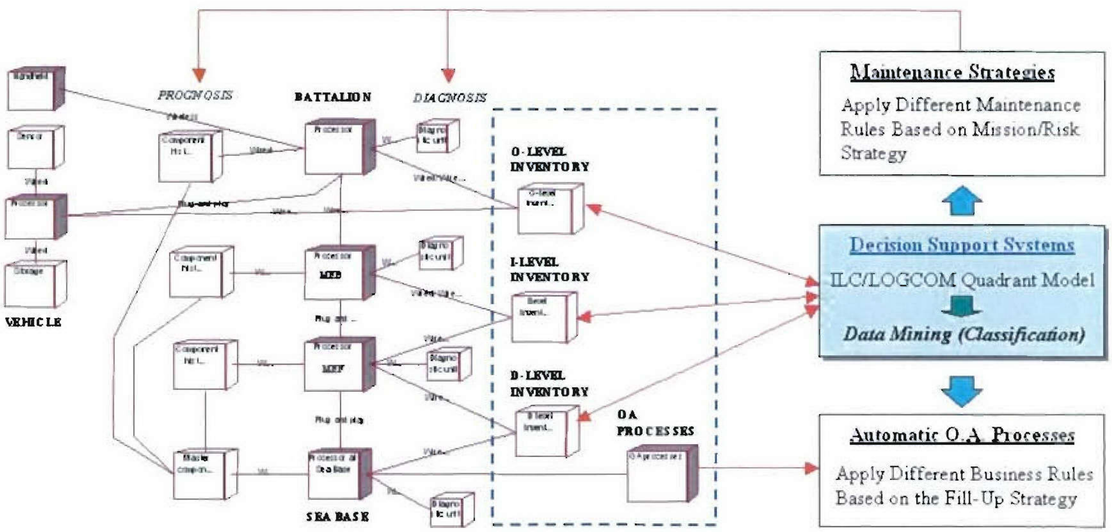

Figure 7.3.3 Decision Support Systems in IDGE Architecture

7.3.7.1 Data Mining Concepts as a Supplement for the Quadrant Model

The Quadrant Model is a currently proposed decision support system for the ILC (Integrated Logistics Capability). However, further refinement and specification rules are required to the Quadrant Model.
There are several known drawbacks in current Quadrant Model. First, it was found that in many cases the attributes for calculating mission or risk value for a part or an item are inappropriate, and in some cases attributes does not exist at all. Second, parts or items lying in the near the decision dividers or extremes of any Quadrant is entirely controlled by the same business rules established for the segment of Quadrant. With respect to the above known drawbacks of Quadrant Model, Data Mining technique is expected to offer following possible advantages and solutions.

First, data mining can consider all related attributes of the part or item. This aspect will help make more reliable and accurate decisions to classify the part or item.

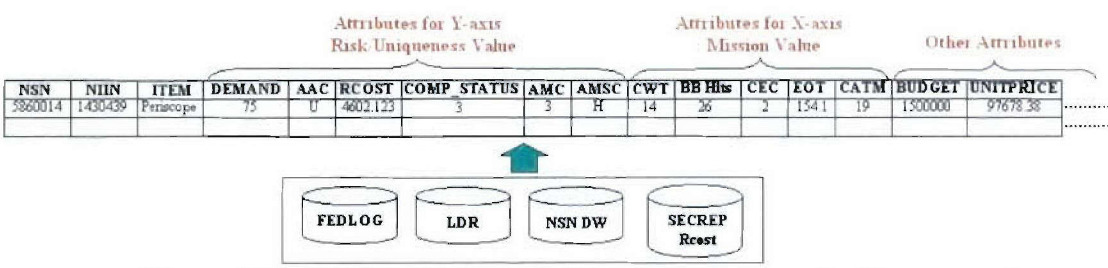

Figure 7.3.4 Considering All Related Attributes of a Part or an Item

Second, once predictor engine for the classification algorithm is developed, then the processes of classifying the parts or items are automatically executed.
Third, classification algorithms can be easily and quickly updated when input information for the algorithm is updated.
Fourth, unlike quadrant model, it is not necessary to modify or change the original value into modified value and weighed value. Based on classification algorithms, categorical value (alphabetic value) also can be used directly in data mining approach.

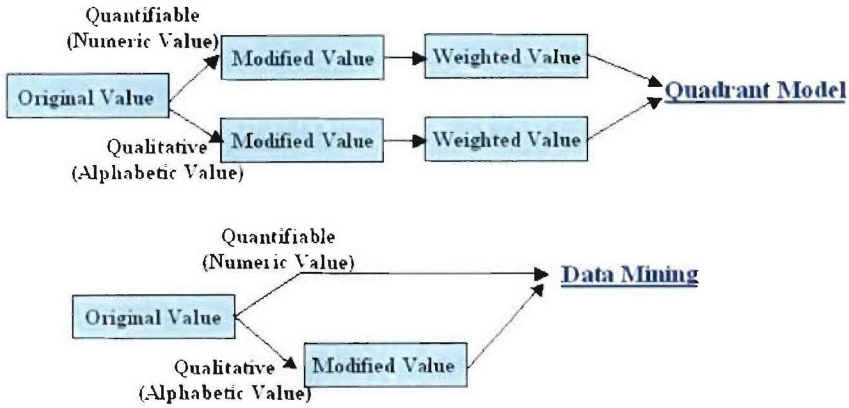

Figure 7.3.5 Comparing the Input Information in Quadrant Model and Data Mining Approach

These various advantages will guarantee data mining classification approach to follow two most important objectives of the decision support systems, 'Timeliness' and 'Real time', in IDGE study.

Data mining brings in greater granularity in the classification and appropriate decision rules and strategies for the specific segments can be applied into maintenance and O.A. processes for the parts or items.

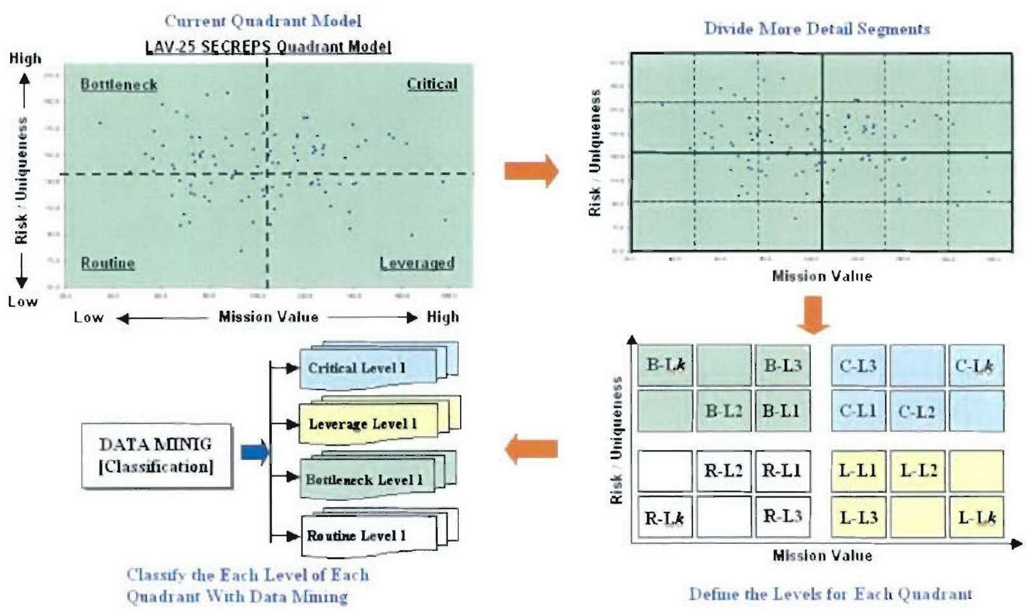

Figure 7.3.6 Comparison Quadrant Model and Data Mining

7.4 Appendix 4 - Sensor Fusion and Fault Diagnosis

7.4.1 Model Updates and Current State of Technology

The model has evolved since its original exposition to the data fusion community. Steinberg and Bowman [83], for example, have recommended the inclusion of a new Level zero processing to account for processing such as pre-detection fusion and coherent signal processing of multi-sensor data. In addition, they suggest a re-naming and re-interpretation of the Level 2 and Level 3 processes to focus on understanding the external world environment (rather than a military-oriented situation and threat focus). C. Morefield [74] has suggested that the distinction between Level 2 and Level 3 is artificial, and that these processes should be considered as a single process. Bowman has suggested that the JDL model can be detrimental to communications if systems engineers focus on the model rather than a systematic architecture analysis and decomposition approach. Despite these remarks the JDL model offers more benefits than disadvantages. There are several modifications to the original JDL model that are under development. Table 5.2 provides an augmented listing of the processes envisioned in an updated model.

Table 7.4.1 Summary of Current State of Multisensor Data Fusion

JDL Process	Current Practices	Limitations & Challenges
Level 1: Object refinement	▪ Sensor preprocessing using standard signal and image processing methods ▪ Explicit separation of correlation and estimation problem ▪ Multiple target tracking using MHT [11], JPDA [6], etc. ▪ Use of *ad hoc* maneuver models ▪ Object ID dominated by feature based methods [30] ▪ Pattern recognition using ANN [57] ▪ Emerging guidelines for selection of correlation algorithms [83], [69] ▪ Promising work by Poore [77] , Mahler [74], Barlow, *et al* [5]	▪ Dense target environments ▪ Rapidly maneuvering targets ▪ Complex signal propagation ▪ Co-dependent sensor observations ▪ Background clutter ▪ Context-based reasoning ▪ Integration of identity and kinematic data ▪ Lack of available ANN training data (for target identification) [57] ▪ No true fusion of image and non-image data (at the data level)
Level 2: Situation Refinement	▪ Numerous prototype systems [50] ▪ Dominance of rule-based KBS ▪ Variations include blackboard systems[68], logical templating [42], and case-based reasoning [189] ▪ Emerging use of fuzzy-logic [78] and agent-based systems [81]	▪ Very limited operational systems ▪ No experience in *scaling up* prototypes to operational systems ▪ Very limited cognitive models [53] ▪ Perfunctory test and evaluation against *toy* problems [50] ▪ No proven technique for knowledge engineering [51]
Level 3: Threat Refinement	▪ Same as Level 2 Processing ▪ Limited advisory status ▪ Limited deployment experience ▪ Dominated by *ad hoc* methods ▪ Doctrine-specific, fragile implementations	▪ Same as level 2 ▪ Difficulty to quantify *intent* [49] ▪ Models require established enemy doctrine ▪ Difficult to model rapidly evolving situations
Level 4: Process Refinement	▪ Robust methods for single-sensor systems ▪ Formulations based on operations research [51] ▪ Limited context-based reasoning ▪ Focus on measures of performance (MOP) versus measures of effectiveness	▪ Difficult to incorporate mission constraints ▪ Scaling problem when many sensors (10^N) and adaptive systems [52] ▪ Difficult to optimally use non-commensurate sensors

	(MOE) [91]	▪ Very difficult to link human information needs to sensor control [37]
Human Computer Interface (HCI)	▪ HCI dominated by the *technology of the week* ▪ Focus on ergonomic versus cognitive-based design ▪ Numerous graphics-based displays and systems [3], [82] ▪ Advanced, 3-D full immersion HCI available [89] and haptic interfaces [28], [56]	▪ Very little research has been performed to understand how human analysts' process data and make accurate inferences. ▪ Creative HCI is needed to adapt to individual users and to provide mitigation of known cognitive biases and illusions [53], [76]
Data Base Management	▪ Extensive use of 4th and 5th generation COTS DBMS ▪ DBMS individually optimized for text, signal data, imagery, or symbolic information (but not the intersection of any two) ▪ DBMS requires extensive tailoring for individual data fusion systems	▪ Need a generalized DBMS capability for text, signal data, images, and symbolic information ▪ Need a software solution to multi-level security

7.4.2 Implementation of Data Fusion Systems

Methods for fusing multi-sensor data are drawn from a wide variety of disciplines including signal processing, image processing, statistics, pattern recognition, and automated reasoning. Many of these techniques have an extensive history, ranging from Bayesian inference (first published in 1763) to fuzzy logic (originating in the 1920s) to neural nets (developed in the 1940s).

7.4.2.1 Aspects of Implementation

Some issues related to the implementation of data fusion systems are addressed in this section. While each data fusion system constitutes a separate problem in systems engineering, there are some general remarks that can be made about requirement analysis, sensor selection, architecture selection, algorithm selection, software implementation, and test and evaluation. These are summarized below.

Requirement Analysis – The initial step for the implementation of any complex system is to perform a requirement analysis. In a typical structured system development approach, formal analyses are performed, culminating in a requirement review and associated documentation. This approach is also recommended for the development of data fusion systems. It should be remembered that data fusion is a derived requirement. Strictly speaking there is no such thing as a data fusion system. Instead there are systems designed to address specific applications or to achieve specified missions. These systems may utilize data fusion algorithms to achieve the application or mission goals. Under this perspective, the system designer must understand what the mission goals or application goals are. What targets or entities must be detected, characterized, or identified? Who are the intended users of the system and what decisions must these users make (to achieve a mission)? This approach focuses on the end-user of the data fusion system rather than on the sensors. All too often, system designers treat a data fusion system as a bucket used to collect or process the sensor data, rather than a system to support an end-user. The requirement analysis must consider the effects of the observing environment, the end-user, the platform (on which the sensors are located), communication constraints, and computing limitations. Key issues include the observing and decision timeline and required level of specificity and accuracy. An excellent discussion of requirement analysis for data fusion system is available in Waltz and Llinas [91].

Sensor selection and analysis – Often, the sensors associated with a data fusion system are specified a priori. This is frequently the case for existing platforms such as aircraft or ships for which a data fusion system must be developed. However, even if the sensors are specified a priori, it is necessary to perform

an analysis of the sensors. In general, there is no single sensor that can detect, locate, characterize, and identify the targets of interest under all circumstances (i.e., there is no perfect sensor). Indeed, the lack of a perfect sensor is one of the motivations for developing a data fusion system. A key component of the system development process is to understand how the sensors perform, both individually and in concert, to contribute to inferences sought by the data fusion system. Sensor selection and analysis must determine what can be observed, and how these observable quantities relate to the targets or inferences of interest. Steinberg (reference) provides an excellent example of this type of analysis for a tactical aircraft. The system designer should develop or utilize high fidelity models that predict how sensors will perform in realistic environments. These models should include the effects of the target, the signal propagation environment, the location of the sensor antenna on an observing platform, and the internal sensor processing. In addition, real data should be collected and analyzed. It is important to understand and accurately model sensor performance. These estimates should be used to help weight the sensor data in the data fusion process. If the performance estimates are not accurate, then it can corrupt all of the down-stream fusion processing.

Architecture selection – Modern data fusion systems often involve distributed sensors and processing systems. Examples include systems on-board a single platform (e.g., an aircraft) linked via a computer network such as Ethernet and unattended ground sensor systems in which multiple sensors are linked using wireless communications. In these systems processing is performed both at the sensors and at a centralized processing computer. A basic question for the system designer is to determine where in the processing flow should the fusion actually be performed? Conceptually, there are three basic types of architectures for data fusion2; (1) centralized fusion, (2) distributed fusion, and (3) hybrid fusion. The centralized fusion architecture involves passing raw sensor data (e.g., time series, images, vectors) from the sensors to a central fusion processing function. In this approach the raw sensor data must be associated, correlated, and fused. The centralized fusion architecture is potentially the most accurate approach for fusion of information (since the raw data are available for processing). However, the centralized approach may require significant communication resources to send the data from the sensors to the centralized fusion process. In addition, the centralized approach may be difficult to actually achieve for non-commensurate sensors.

In the distributed fusion approach, sensor data are processed to result in state vector estimates for observed targets. These estimates may contain estimates of the target's position, velocity, attributes, and identities. In the distributed fusion architecture the processing is effectively distributed among the sensors and other fusion processing computers. Distributed fusion reduces the amount of information that must be communicated between the sensors and the fusion processor (i.e., instead of raw data sent from the sensors to the fusion processor, only state vectors or feature vectors are sent from the sensors to the fusion processor). In addition, distributed fusion is convenient for processing information from diverse types of sensors. A potential problem with distributed fusion is a loss of accuracy because the raw data are not available for fusion.

Finally, hybrid fusion architectures combine both a centralized approach and a distributed approach. This allows the system to limit communication resource utilization (using the distributed mode of operation), or to improve accuracy by processing the raw sensor data. Hybrid fusion provides the most flexible type of architecture at the expense of added computational overhead to address the decision processes associated with operating the hybrid processing.

How does one select an appropriate architecture for a fusion system? This is a basic problem in system engineering. Steinberg and Bowman [83] provide basic guidelines for system design and architecture selection. Bowman in particular has developed an approach that involves a hierarchical decomposition of fusion system into nodes with an allocation of functions to nodes based on the characteristics of the sensors, communications, and processing systems. The system designer should explicitly consider alternative architectures for the fusion system to be designed. Each alternative can be modeled to evaluate the system effectiveness and the demands on system resources such as computing and communications.

Algorithm selection – Perhaps the most controversial issue in data fusion is the selection of algorithms. There are many algorithms that can be applied to the different processes within the data fusion process. For example, many different algorithms have been developed for target tracking and target identification. Even for a function as basic as data correlation, a wide variety of techniques can be applied. Llinas et al [69] identified over 50 different techniques used for data correlation and association. The methods involve different assumptions concerning the nature of the input data, understanding of the uncertainty of the input data, available computing resources, and other factors.

One challenge in the implementation of a data fusion system is how to select from these different techniques. Hall and Linn [41] provide some general guidelines for the selection of data fusion algorithms. However, there is no prescription that provides a unique specification of which algorithms to use. Unfortunately, many proponents of specific techniques (e.g., Bayesian inference, Dempster-Shafer's method, multiple-hypothesis tracking, etc.) argue that their method is the only method to be used for every application. The choice of a set of algorithms for a fusion system must be based on a system's engineering approach. The designer must have a clear understanding of the algorithms (including the underlying assumptions, required a priori data, etc.), the processing constraints of the fusion system, and the limitations in the observing environment. In some cases, sophisticated algorithms may be mathematically appealing, but cannot be effectively used because the requisite a priori data is not available. Hall and Linn [41] provide an example of how easily complex algorithms can be corrupted by input of incorrect data. Special care must be taken to understand how fragile an algorithm is to variations in the input data. A recommended approach is to deliberately identify and tradeoff candidate algorithms prior to the selection of an algorithm suite for a data fusion system.

Software implementation – Implementation of a data fusion system generally involves development of an extensive set of software. Use of COTS [53]; care must be taken not to follow the trap of using too much existing data fusion software; In general these are "point solution" and not particularly portable to other applications. There does not exist the equivalent of a numerical methods library for data fusion (although there are some tool kits – Khoros and the data fusion tool kit). In typical implementations the bulk of the software will be for the infrastructure.

Test and evaluation (T&E) – T& E involves the traditional problems of testing and evaluating large-scale hardware and software systems. Special challenges for evaluating data fusion systems include; (1) evaluating single versus multiple sensor performance, (2) evaluation the effectiveness of context-based reasoning, (3) obtaining sufficient training data for pattern recognition algorithms, and (4) understanding how data fusion performance is affected by varying performance sensors.

Hall, Kasmala and colleagues [40] developed a visual programming data fusion tool kit. This tool kit supports rapid prototyping and experimentation. The tool provides a collection of algorithms for signal conditioning, feature extraction, and data fusion. It has been applied to CBM data including gearbox data, data from NASA Ames Research Center wind tunnel equipment, and data collected from a rotorcraft gearbox. The tool provides a "point and click" graphical interface for creation of processing flows, selection of algorithms, and display of output results. The top level graphical interface is shown in Figure 5.2.

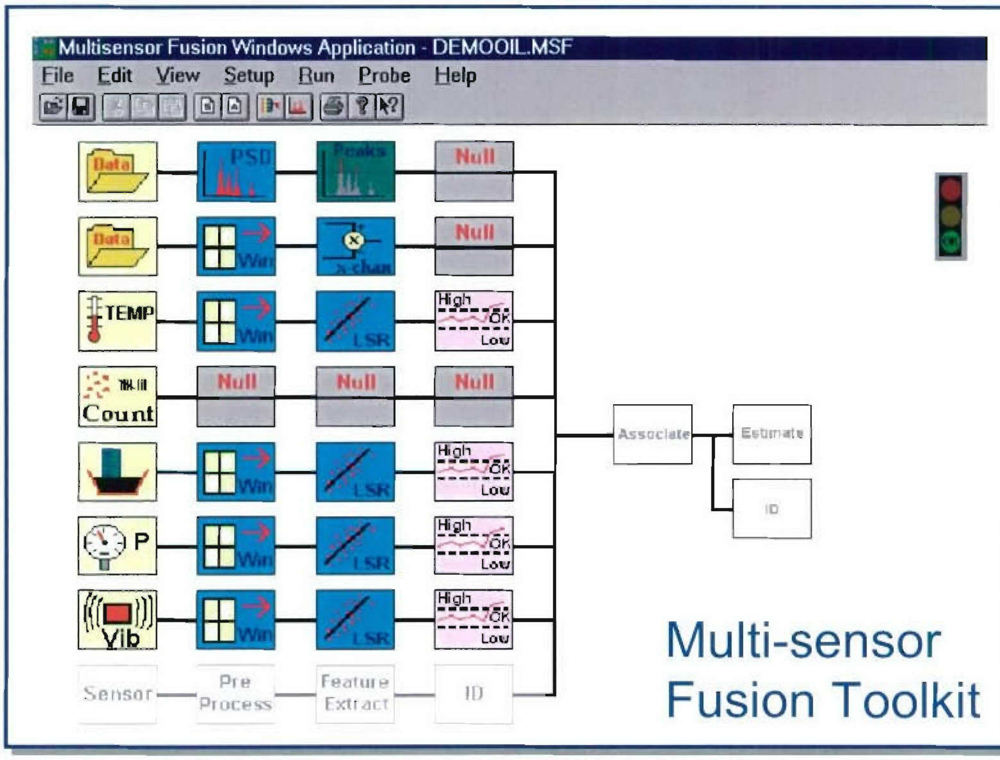

Figure 7.4.1: Penn State ARL's Multisensor Fusion Toolkit.

7.4.3 Condition-Based Monitoring

Development of technology to enable the implementation of condition-based maintenance for mechanical systems is of vital importance to the department of defense and the navy. Maintenance and overhaul of large platforms and weapon systems such as the CVN-76 comprise over 35 per cent of the projected life-cycle cost. This exceeds the original platform design and development costs. The ability to monitor the health of mechanical equipment and to accurately predict remaining useful life will allow a major reduction in maintenance costs while simultaneously increasing safety and improving mission readiness for key assets.

The importance of accurate health assessment and prediction for electrical and mechanical systems has been cited in numerous national defense plans and studies. For example, the 1996 United States Defense Technology Plan objectives included an 80% reduction in aircraft mechanical mishaps and a 35 % reduction in spare parts inventories. A 1995 OASN study on safety and survivability of aircraft recommended a need to achieve a 30 % reduction in lifecycle maintenance costs. Multiple safety reports have identified the impact of undetected maintenance problems that resulted in the loss of life for military personnel. A 1996 United States Air Force Integrated Product Team report identified 58 preventable mishaps resulting in the loss of 16 lives and an equipment cost of $ 365 M.

Two recent documents cite the need to accelerate the application of embedded diagnostics and condition-based maintenance. The U. S. Army VcoS memorandum, dated April 30 1998, assert that, "... include embedded diagnostics on all new and retrofit equipment..." The memorandum further states, "... We will not field systems or retrofit equipment without embedded diagnostics. If a tradeoff must be made because of funding, Army policy will be to obtain fewer, more capable systems." The US Navy OPNAVINST 4700.16-policy document on Condition-Based Maintenance dated May 6 1998 establishes a navy policy to implement CBM. The document asserts that, "CBM Methodology shall be used to determine maintenance decisions and reduce scheduled maintenance and manpower requirements."

The policy also indicates that, "Chief of Naval Operations (CNO) will fund naval programs, processes, and enabling technologies proven applicable and effective in supporting the maintenance, manning, and cost reduction objectives of this instruction."

CBM has enormous commercial application for the transportation and manufacturing industries. Demonstration of CBM enabling technology will provide the basis for improved automobiles, safer commercial aircraft, improved automation of industrial processes, and many other commercial applications. Companies such as Oceana Sensor Technology, Honeywell, Boeing, Lockheed Martin and many other companies are investing in this technology. Commercial products will include new sensors, health monitoring systems, improved automobiles and aircraft, and new factory automation. Overall, CBM technology improvements will lead to increased safety, increased productivity, and reduced costs of products.

Implementation of condition-based maintenance involves predictive diagnostics (i.e., diagnosing the current state or health of a machine and predicting time to failure based on an assumed model of anticipated use). CBM and predictive diagnostics depend on multisensor data—such as vibration, temperature, pressure, and presence of oil debris—which must be effectively fused to determine machinery health. Indeed, Hansen et al. suggested that predictive diagnostics involves many of the same functions and challenges demonstrated in more traditional DoD applications of data fusion (e.g., signal processing, pattern recognition, estimation, and automated reasoning) [54]. This section presents the potential for technology transfer from the study of CBM to DoD fusion applications.

CBM involves monitoring the health or status of a component or system and performing maintenance based on that observed health and some predicted remaining useful life (RUL) [23]. This predictive maintenance philosophy contrasts with earlier ideologies, such as corrective maintenance—in which action is taken after a component or system fails—and preventive maintenance—which is based on event or time milestones. Each involves a cost tradeoff. Corrective maintenance incurs low maintenance cost (minimal preventative actions), but high performance costs caused by operational failures. Conversely, preventative maintenance produces low operational costs, but greater maintenance department costs. Moreover, the application of statistical safe-life methods (which are common with preventative maintenance) usually leads to very conservative estimates of the probability of failure. The result is the additional hidden cost associated with disposing of components that still retain significant remaining useful life.

Another important consideration in most applications is the operational availability (a metric that is popular in military applications) or equipment effectiveness (more popular in industrial applications). High total cost is incurred when overly corrective or overly preventative maintenance dominates. These also provide a lower total availability of the equipment. On the corrective side, equipment neglect typically leads to more operational failures during which time the equipment is unavailable. On the preventative side, the equipment is typically unavailable because it is being maintained much of the time. An additional concern that affects availability and cost in this region is the greater likelihood of maintenance-induced failures.

The development of better maintenance practices is driven by the desire to reduce the risk of catastrophic failures, minimize maintenance costs, maximize system availability, and increase platform reliability. These goals are desirable from the application arenas of aircraft, ships, and tanks to industrial manufacturing of all types. Moreover, given that maintenance is a key cost driver in military and commercial applications, it is an important area in which to focus research and development efforts. Such cost savings have motivated the development of CBM systems; furthermore, substantially more benefit can be realized by automating a number of the functions to achieve improved screening and robustness.

Extensive research has been performed to address the condition-based maintenance problem. Research has included work in advanced sensors, signal processing, multi-sensor data fusion, automated reasoning, mechanical models, and non-linear dynamics. Indeed, similar research was conducted at the Pennsylvania State University funded by the Office of Naval Research under the auspices of a Multi-disciplinary University Research Initiative (MURI) program on Integrated Predictive Diagnostics (IPD). Information on this project may be found at the web site:

www.arl.psu.edu/areas/soa/conditionmaint.html.

This site contains a summary of the research and list of publications. Various assessments of the state of the art in condition-based maintenance have been conducted. See for example the work by Hall [58] and by Byington and Garga [16]. Additional information is provided by Kumara et al [64], [15], [73], and [87].

7.4.3.1 Constituents of a CBM System

CBM uses sensor systems to diagnose emerging equipment problems and to predict how long equipment can effectively serve its operational purpose. The sensors collect and evaluate real-time data using signal processing algorithms. These algorithms correlate the unique signals to their causes—for example, vibration sideband energy created by developing gear tooth wear. The system alerts maintenance personnel to the problem, enabling maintenance activities to be scheduled and performed before operational effectiveness is compromised.

The key to effectively implementing CBM is the ability to detect, classify, and predict the evolution of a failure mechanism with sufficient robustness—and at a low enough cost—to use that information as a basis to plan maintenance for mission- or safety-critical systems. "Mission critical" refers to those activities that, if interrupted, would prohibit the organization from meeting its primary objectives. "Safety critical" functions must remain operational to ensure the safety of humans (e.g., airline passengers). Thus a CBM system must be capable of:

- Detecting the start of a failure evolution
- Classifying the failure evolution
- Predicting remaining useful life with a high degree of certainty
- Recommending a remedial action to the operator
- Taking the indicated action through the control system
- Aiding the technician in making the repair
- Providing feedback for the design process

These activities represent a closed-loop process with several levels of feedback, which differentiates CBM from preventive or time-directed maintenance. In a preventive maintenance system, time between overhaul (TBO) is set at design, based on failure mode effects, criticality analyses (FMECA), and experience with like machines' mortality statistics. The general concept of a CBM system is shown in Figure 5.3.

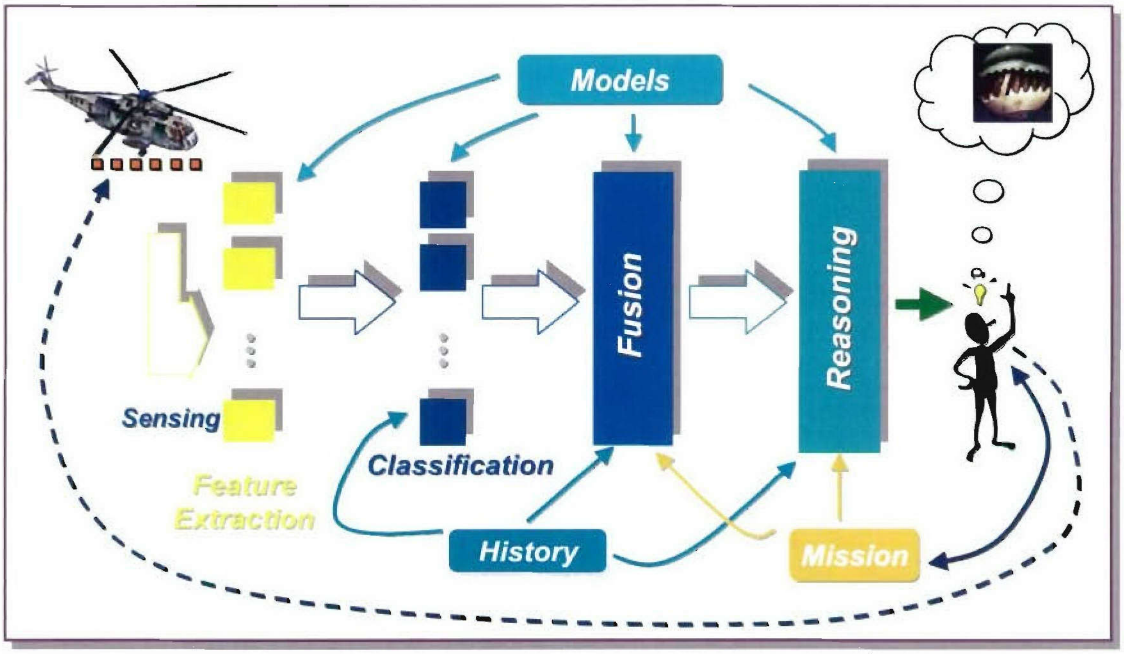

Figure 7.4.2 Concept of a Health Monitoring System.

The intelligent monitoring system shown in Figure 5.3 has multiple components and functions including; (1) active and passive sensors, (2) signal processing and feature extraction, (3) pattern classification, (4) multi-sensor data fusion, (5) automated reasoning, (6) models, (7) historical data input, (8) mission constraints, and (9) human-in-the-loop decision making.

Active and passive sensing – Many different active and passive sensors are applicable for monitoring a mechanical system. Impending failure conditions cause excessive vibration ([95], [12]), noise, heat, debris in lubricants ([1], [79], [20]), and other symptoms such as acoustic emissions. As might be anticipated a wide variety of sensors have been utilized to monitor such systems. Unfortunately, there are a number of challenges in sensing. First, while mechanical failure is initiated at a materials level, typical sensors observe the results at a subsystem or platform level. Figure 5.4 illustrates the hierarchy from the material level (where failures are initiated) and the subsystem to platform levels where failure effects are observed.

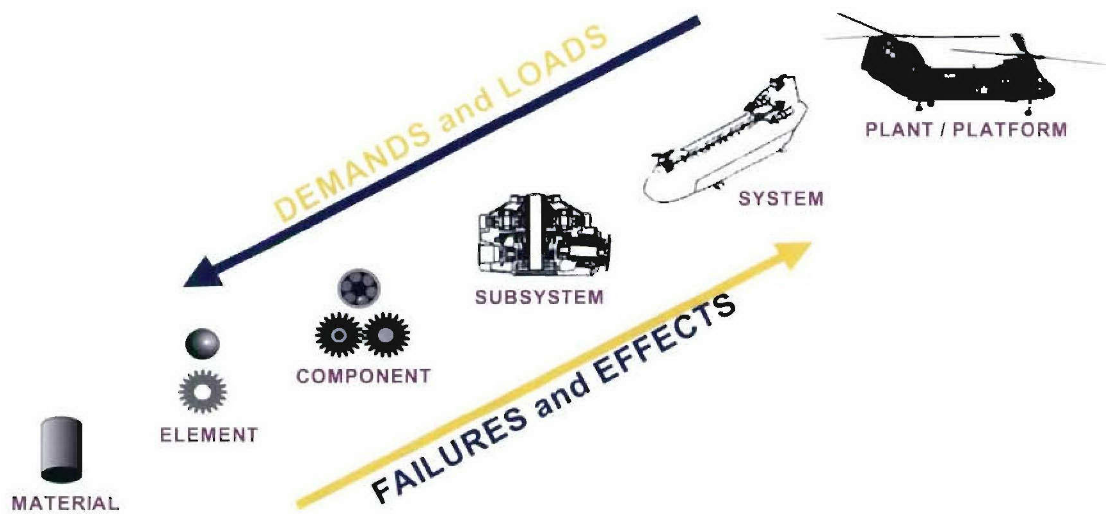

Figure 7.4.3 Material to Platform Hierarchy

Byington and Garga [16] describe an experiment performed with a simple two-gear mechanical gearbox (called the mechanical diagnostic test bed). In multiple experiments, a two-gear box rated at 10 horsepower was systematically overloaded using a 30 horsepower motor and an applied 70 horsepower load. The gearbox was fitted with approximately 50 sensors including accelerometers, microphones, and torque meters. Information about this experimental test bed can be found at the web site:

http://www.arl.psu.edu/areas/soa/facilitiestools.html#Mechanical.

Under controlled conditions, gearboxes were systematically driven to failure. Even though the load conditions were identical and the sensors were placed in identical locations on the gearboxes, the output from the sensors differed markedly from one transmission to another. Apparently, minor differences in the gearbox housings acted as a non-linear amplifier to result in significantly different readings from the sensors from one test run to another. Hence the idea of using a simple threshold scheme to monitor excess vibration is not a reliable means for detecting failure conditions.

Signal processing and feature extraction – The observational environment for intelligent monitoring systems can very challenging. For example the ambient vibration on a rotorcraft is nearly 1000 gs. The differential vibration associated with an incipient gear tooth crack may only be ¼ to 1 g. Hence, the signal to be detected has a 1000 to 1 noise to signal ratio. Moreover, the vibrations associated with a rotorcraft transmission involve the fundamental and harmonic frequencies of tens of gear meshes. In general the signals observed by monitoring sensors are very complex and corrupted by noise and interfering signals ([36], [70], [92]). Hence, extensive signal processing may be performed to reduce noise, focus on frequencies or segments of interest, and perform feature extraction. Numerous features have been utilized for condition monitoring including features in the time domain, frequency domain, and the time-frequency domain.

Pattern classification – After the sensor data are conditioned and features are extracted, then pattern recognition techniques such as neural networks may be used to perform fault detection and identification. While numerous pattern recognition methods have been applied to monitor mechanical systems, the key to success involves selection of robust features. One problem in such selection is that features useful in so-called seeded fault experiments may be brittle or fragile in failure transition experiments ([71], [47], [17], [18], [31], and [46]). Seeded fault experiments involve comparing the results of a normal or no-fault machine with the observations from a machine in which a fault condition has been deliberately planted (or seeded). By contrast, transition experiments attempt to observe the behavior of a feature vector as a machine transitions from normal operation to a failure condition (e.g., induced by overstressing the

machine). In general, fault classification based on information from a single sensor tends to be ambiguous with the potential for a high false alarm rate.

The concept of feature extraction and pattern recognition for fault classification is illustrated in Figure 5.5 below.

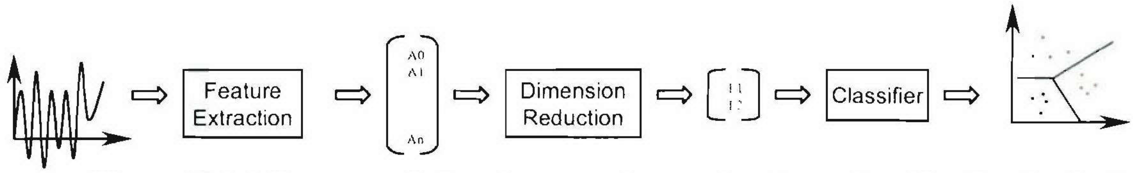

Figure 7.4.4 Concept of signal processing and pattern classification for fault identification

Data from a sensor such as an accelerometer are processed using one or more signal processing algorithms (e.g., extraction of Fourier coefficients, computation of auto-regression (AR) coefficients, wavelet transformations or other methods). Subsequently a feature vector is computed (e.g., a vector of Fourier coefficients). This feature vector is input to a classifier such as a neural net or clustering algorithm. Ideally, the feature vector can be mapped into separate locations in feature space, with each location corresponding to a different fault condition (or to an indication of equipment health). This is illustrated in the right hand side of Figure 5.5. In practice there are many issues with this approach. Selection of appropriate features, collection and utilization of training data and choice of classifier are all challenging problems (see for example, [31], [46], [27], and [57]). Typically there is never sufficient training data to develop a robust classifier. Hence, ad hoc substitution methods are used to generate a synthetically large training set.

Multi-sensor fusion – It is intuitive that the use of multiple sensors would improve the ability to determine the health of a mechanical system and to predict time to failure. Improved results should be obtained by expanding the physical baseline of observations and also from combining information from multiple sensors of the same type. Indeed, experiments conducted at The Pennsylvania State University under a Multidisciplinary University Research Initiative grant funded by the Office of Naval Research confirm these anticipated benefits (see [20], [35], [39], [21], [16]). Fusion can be performed at a variety of levels from fusion of raw data to feature-level and decision-level fusion. Byington and Garga [16] provide details on algorithms for fusion at all of these levels. The experiments demonstrate that data fusion can improve the accuracy of fault classification, reduce false alarms, and partially mitigate the effect of poorly performing sensors.

Automated reasoning – Context-based reasoning is important to assist in the monitoring process. Real mechanical systems undergo numerous changes during their operation (e.g., during the course of a mission and during their life span). Symptoms that are meaningful during one part of a mission are meaningless during another part. An example is the vibrations experienced during an aircraft takeoff or landing versus level flight. Hence, the output of sensors and pattern recognition or fusion algorithms cannot simply be taken at face value. Instead the use of automated reasoning assists in interpreting the results (see for example, [47]). Implicit reasoning techniques such as neural networks or pattern classifiers have been applied for fault detection and classification. In addition, explicit reasoning techniques such as fuzzy-logic rule systems, parametric templates, and case-based reasoning methods have also been applied. Garga et al ([35], [47]) have developed hybrid-reasoning methods to improve the performance of both explicit and implicit reasoning methods. In addition, Hall et al [48] have argued that the use of negative reasoning (viz., reasoning about information that is not observed or conditions that do not appear to be occurring) can improve the diagnosis of mechanical systems. They point out that expert diagnosticians often use negative reasoning.

Modeling – In order to understand the condition of a system and to predict future evolution, models of the system being monitored are required. Ideally, models should include information about the machine construction and makeup, the transformations from platform-induced demands to materials level effects.

Models should allow prediction of observations based on hypothesized fault conditions (observation models). Finally, dynamic models are sought to support prediction of the system evolution (viz., state transition models). Unfortunately, such models rarely exist. Much work has been performed to develop materials level models (e.g., crack growth models, stress/strain models, and finite-element models [127]). However, there are no general models to link materials phenomena to platform results, or to predict observations from hypothesized failure conditions. Finally, system-level failure evolution models do not exist. Hence, it is necessary to combine limited physics-based models with more ad hoc models based on the experience of trained mechanic (see [25], [8], [9], [7], [10], [26]).

Historical data input – Historical maintenance information and information about the previous missions and system use can be used to assist in interpreting the current state and prediction of future conditions. An aircraft that has been utilized for routine flights may have a significantly different condition than an aircraft flown on combat missions – even though they nominally have experienced the same number of flight hours. Moreover, long-term data such as oil debris analysis may be useful to interpret the condition and evolution of a machine. Byington and Garga [16] point out that for mechanical systems such as gearboxes, the morphology of wear particles in circulating oil is different for benign wear compared to those generated by the active wear associated with pitting, abrasion, scuffing, fracturing and other abnormal conditions. Roylance and Raadnui [80], for example, correlated particle features (quantity, size, composition and morphology) with wear characteristics (severity, rate, type, and source).

Mission constraints – A key for military systems is mission constraints. While commercial systems may be able to accept recommendations for maintenance, during military operations mission constraints may severely limit the possible maintenance or mitigation actions. Hence, mission constraints and information must be considered when performing context-based reasoning about a system being monitored.

Human-in-the-loop decision-making – Despite advances in intelligent monitoring systems, there remains a role for the human to act as a decision-maker. The pilot, system operator, or maintenance technician may be involved in interpreting the results of the intelligent monitoring system and making final decisions related to system operation or maintenance. The definition of this role is part of the overall systems engineering process in designing a system. For military systems in particular, it is desired for a human operator to be capable of overriding recommendations by an intelligent monitoring system in order to accomplish a mission (even when the act of override may endanger equipment). Byington et al [19] provides an excellent discussion of these issues as they relate to flight crews.

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